AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

339.

(Vol. XV.—August, 1886.)

ON THE WORK DONE FOR THE PRESERVATION OF THE DAM AT HOLYOKE, MASS., IN 1885, AND ON SOME STUDIES FOR A NEW STONE DAM FOR THE SAME PLACE.

By CLEMENS HERSCHEL, M. Am. Soc. C. E.

READ FEBRUARY 17TH, 1886.

Friends of mine have thought that a description of the work done at Holyoke, Mass., on the dam of the Holyoke Water Power Company, in the summer of 1885, would prove interesting to the profession. I have had my doubts about it, for the reason that this was one of that class of engineering works which cannot readily be repeated; which makes no show after it is done—indeed, leaves little or no trace upon the surface of its very existence; and involves no search or delving in the hitherto unexplored regions of mathematical or other sciences. But if this record of a highly useful work, well done, be

> "Something that perhaps another,
> Sailing o'er life's solemn main,
> A forlorn and shipwrecked brother,
> Seeing, shall take heart again,"

I shall be glad to have written it. And for the purpose of adding other possibly interesting or useful matter, I have included some historical accounts of the dam at Holyoke—some lessons that may be learned from thirty-six years of its life—together with an account of some experiments made in the line of selecting a design for a new stone dam for the same place. I have been the more ready to do this, as the dam at Holyoke, although the largest over-fall dam in the world, as far as I know, has not, that I am aware of, hitherto been described in engineering literature.

Water Power at Holyoke, Mass.

The Holyoke dam and water power is the outcome of that spirit of enterprise for manufacturing, which swept like a great wave over the New England States between the years 1820 and 1850, consequent upon the successful introduction of cotton manufacturing at Waltham, Mass., and at other places. The works of the Hadley Falls Company, in founding the present City of Holyoke, were built, moreover, at the very time of extreme high water-mark of this era of enterprise for manufactures. The water power at Lowell, Mass., had come under the control of a company, organized simply and solely to administer a water-power, in 1845. Two years later saw the completion of the dam at Lawrence, Mass., by the Essex Company, another water-power company. And the same year, 1847, a charter was obtained, creating the Hadley Falls Company, for the purpose (amongst others) of constructing and maintaining a dam across the Connecticut River, at the point where now is Holyoke. It is but just to say, in passing, that this last was the work, principally, of James K. Mills, then a merchant of Boston, but born and brought up in that rugged school of life, "up among the Berkshire Hills." He became the leader in the subsequent work and enterprise, and remained so until the year 1857, ill-fated to many another such a pushing, restlessly active, mind and man.

In 1853, the directors of the company published a description of the dam and canals, and of the young city, which is now out of print. It is in many ways interesting reading at the present day, wherefore I do not hesitate to quote from it. After describing the soil and drainage area of the Connecticut River, its central location and other advantages, and noting the fact that while in Massachusetts every fall in the smaller rivers, "indeed every 'privilege' upon the smallest and most insignificant streams have been seized upon for the use of some mill or factory,

the noble Connecticut had been long almost neglected," they go on to say: "This neglect would be inexplicable, were it not obvious that the extraordinary magnitude of the enterprise, required, in a corresponding degree, more than ordinary forethought, skill and capital, for its accomplishment. But it is equally obvious that such an enterprise, when carried out, should be successful and productive in a corresponding degree."

Under a charter granted in 1792, the Connecticut River had been made navigable to small boats and rafts, eventually, up to Wells River, Vermont; and up past what is now Turner's Fall, Mass., probably prior to 1800. In 1797 the tolls had already amounted to about $5 000. The works at South Hadley, Mass., opposite the present City of Holyoke, were the property of the "Proprietors of the locks and canals on the Connecticut River." This company had had its ups and downs, like many another. After a lot of assessments on the "proprietary shares," just as these things go now-a-days, the tolls began to come in, and later on, the dividends to go out. In 1815 the tolls were $11 000; in 1817, $15 000; in 1833, $20 000, with $15 000 of dividends paid that year. This was probably the best year the company saw, for with the facilities afforded by the railroads built soon after, the crude navigation afforded by the works of the proprietors of the locks and canals on the Connecticut River could in no way compete. But in 1848 it was ready to and did sell and convey its real estate to the Hadley Falls Company, the individual stockholders at the same time selling their stock to the principal men in the new company.*

The First Dam at Holyoke.

Quoting from the pamphlet above named: "It was at first contemplated to throw across the river a temporary dam, which, while it would

* As an example of how things were done in the olden time, I mention the fact that during the process of conveying the property and franchises of the proprietors to the present Holyoke Water Power Company, in 1883, it became my duty to look up the stock. Do what I would, I could not find more than 503 shares, and yet the property had been divided into 504 shares in 1792. There was no help for it but to begin at the beginning and search the records, when behold:

I, the within named James Bull, of Hartford, in the State of Connecticut, in consideration of a valuable sum of money, viz.: two hundred and twenty dollars ($220), received to my full satisfaction, of Jonathan Dwight, Esq., Treasurer of the Lower Locks and Canals on Connecticut River, the receipt whereof I do hereby acknowledge, do assign and make over all my right and title to the within mentioned share, No. 80, and all privileges and rights to which I am entitled by virtue thereof, to him the said Jonathan Dwight, Esq., or his

serve as a protection to the erection of one more substantial below it, would answer the purpose of the company until such permanent dam should be completed. The first dam was accordingly built with less regard to strength than the result proved would have been prudent. It was not able to resist the force of the river, and was carried away after the gates were closed. The shutting of the gates occurred earlier than had been designed, in consequence of a freshet in the river." To this I may add, on reliable authority, that it was, after all, fortunate that the dam gave way, because the coffer-dam upstream from the head gate-house was rapidly breaking up—the head gates were not yet in their grooves, nor was the upper level canal done—and had this coffer-dam failed, it would have turned the whole river over the site of the projected new city, and would have done incalculable damage. I know of no drawing that would show the construction of the first dam at Holyoke. The gates were shut at about 10 A. M., November 16th, 1848; the water had risen to within 2 or 3 feet of the top by 3.20 P. M.; when all but about 75 feet at one end and 150 feet at the other, rolled over and floated down stream on the crest of a wave about 8 feet high. Some newspaper communications with regard to its failure appeared in the New York *Tribune* of November 20th, 21st and 25th, 1848, but they are not conclusive as to the cause.

Tradition has it, that this dam was, in its framing, very much like the coffers herein portrayed, and used on the dam in 1885, and that the principal cause of the failure was the too steep slope given the upstream face of the dam. The loss to the company by the giving way of this

---

successors in office, to have and to hold to him and them so long as the corporation shall remain a body politic.

Witness my hand and seal, this 11th day of December, Anno Domini, 1807.

JAMES BULL. [SEAL.]

Signed, sealed and delivered in the presence of }
THOMAS BULL,
CHARLES BULL.

STATE OF CONNECTICUT, Hartford County, Hartford. } *ss.:*

December 11th, 1807, then personally appeared James Bull above-named, and owned the foregoing instrument to be his free act and deed.

Before me,
ELISHA COLT, Justice of the Peace.

In other words, the worthy Treasurer, instead of watering the stock, which is the modern pastime, had valiantly commenced to condense it, and had started the bull movement by boiling the stock down to the extent of one share.

first dam was at first called $50 000 or $100 000, but was finally stated, on what seems good authority, as having amounted to $38 000. Day labor at the time was about 75 cents a day, and a strike occurred on reducing this to 70 cents a day.

Second and Present Dam at Holyoke.

Quoting again: "The company immediately proceeded to the erection of the present dam upon a very different and a much stronger plan, which, as it has already defied the strength of the current of the river for three years, will no doubt remain permanent indefinitely. This dam was begun and finished in the summer of 1849. Its length is 1 017 feet, about one fifth of a mile. At the two ends are abutments of heavy masonry, the amount in both being nearly 13 000 perches. Between these abutments it is composed of heavy timbers, the smallest being 12 inches square, which are built up in such a way as to present on the upper side a surface of plank inclined at an angle of 21 degrees 45 minutes to the water of the river. The timbers which cross the river transversely, are supported by other timbers at right angles with them, which are arranged in 170 sections, 6 feet apart. The ends of these timbers, parallel with the course of the river, are spiked to the solid rock at the bottom of the channel with 1¼-inch iron bolts, of which there are nearly 3 000. Four million feet of timber are contained in the structure, all of which, being under water, is protected from decay. Gravel was filled in and well pounded down at the foot of the dam, which is still further protected by the addition of a mass of concrete. As the timber-work went up, the whole foundation, 90 feet in extent, and all open spaces were packed solidly with stone to the height of 10 perpendicular feet. The planking of the upper portion of the dam was doubled (trebled) to a thickness of 18 inches of solid timber (3 layers of 6 inches each) all trenailed, spiked, and strongly bound together. The rolling top or combing was then covered with sheets of boiler-plate, placed side by side, and extending the whole length of the dam. The graveling in the bed of the river begins 70 feet above the dam, and is continued over 30 feet or more of its sloping surface, which is 92 feet in length from the foot to the crest of the dam.

"During the construction of the dam, the water was allowed to flow through gates in it 16 by 18 feet, of which there were 46 in all, when the work was finished. At twenty-two minutes before one o'clock, in the

afternoon of October 22d, 1849, the engineer gave a signal and half of the gates were closed, another signal immediately followed and the alternate gates were also closed—the river ceased its flow, until its water, gradually collecting, rose upon the face of the dam, and finally fell in a broad sheet over its crest.

"The firm basis upon which this dam stands, founded, as it is, upon the solid rock at the bottom of the river; the strength and solidity of the structure by which the several parts support each other and the whole is bolted to its foundation; the thick bed of gravel on the upper end of the dam, and the filling in with stone between the timbers; the substantial manner in which the work was executed under the superintendence of careful engineers; the effect of the water upon the material of which it is constructed, rendering it practically imperishable; and the safety with which it has passed through the severe trials of the freshets of three years—these things leave no room for doubt as to its permanence and security.

"At the western end of the dam, as is indicated upon the plan at the end of this pamphlet, the water of the river is drawn out in a canal for the supply of the mills. The water is conveyed into this canal by means of 13 gateways. There is also a stone lock. The sides of the canal are built of solid masonry. The width is 140 feet at the bottom and 144 feet at the surface. The canal is designed for 20 feet of water. * * * * * * * The exact fall from the river above the dam to the still water below is 59.9 feet. Of this, 20 feet are used by the mills on the upper level, leaving a fraction less than 40 feet fall for the most southerly mill on the lower level. The mills on the northern end of the lower level, of course, do not have so much fall, as they deliver the water directly into the river, which is higher just under the dam than below, on account of the rapids. All of the mills at the lower level, however, will have at least 30 feet of effective fall throughout the year." At a later day this project was changed to a system of three levels, the middle set of mills having 12 feet fall. There are to-day five different kinds of falls used from the canals of the Holyoke Water Power Company: from each of the three levels directly into the river; from the first into the second, and from the second into the third level.

A cross-section of the dam accompanies the description above given, which has been reproduced on Plate LII. Another illustrated description of the work, showing also the apparatus used for dropping the gates,

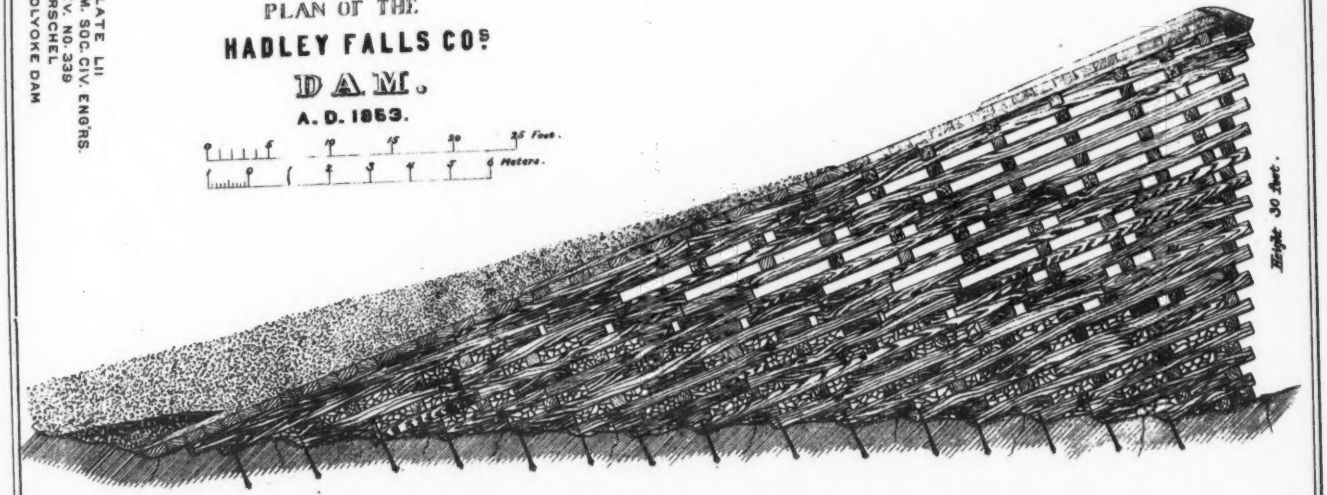
PLATE LII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM

PLAN OF THE

HADLEY FALLS Co's

DAM.

A. D. 1863.

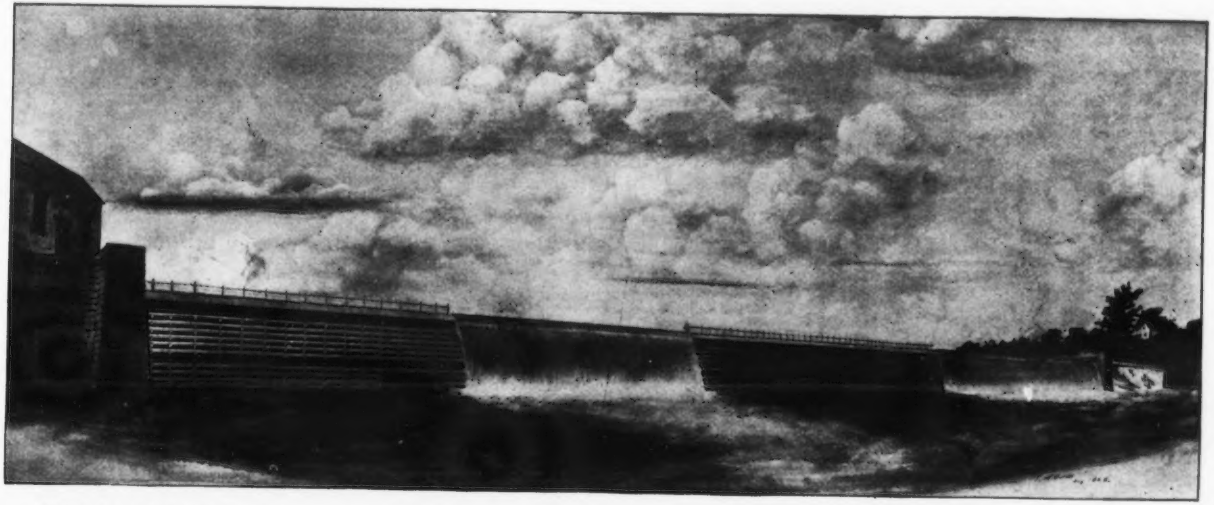


may be found in the Springfield *Republican* of March 6th, 1850, printed also in the *Scientific American* of the preceding week. The total cost of the dam is given at $150,000, which would represent at least $250,000, I should judge, at the present day. This account states: "The dam leaks but very little, not a whit more than is desirable for its preservation." And the Springfield *Republican* of October 23d, 1849, describing the closing of the gates and completion of the dam had said: "The dam leaks a little, not so much as the one which went out last year. This is considered no fault, as a sufficient leak is necessary to keep all of the timbers of the dam bathed in water to prevent rot. If it does not leak enough for this it will be made to leak more by boring holes through." How far all these anticipations of a preservation of the dam by its being constantly under water were realized, will appear presently. The agent of the company at the "New City" was Mr. John Chase. The chief engineer was Philander Anderson, who entered West Point in 1827, but did not graduate. In the designing of the works at Holyoke, in the excellent lay-out of the canals and streets of the new city, Mr. Anderson has left an imperishable monument to the good qualities in him. His was one of those natures which are their own worst enemy, and it is not known that he did later important work. A Mr. Foote is mentioned as assistant engineer, and of A. C. McNary, superintendent of mechanics, it is said, that "to him great praise is due for the perfection with which the work was accomplished."

Experience of 1849 to 1868.

November 12th, 1849, already saw 6 feet of water over the new dam, and the windows in Springfield, eight miles away, rattled at the rate of 128 vibrations per minute in consequence of the sheet of water passing over without opportunity being afforded for the air to pass freely underneath from one abutment to the other. It was even claimed that the noise made by the water falling over the new dam was heard in Hartford, Conn., 34 miles away. The following May there was 8½ feet of water on the dam. Four years later, 1854, there was 10½ feet, and in April 1862, there was 12½ feet, which sent the water through the doors of the gate-house, and which has remained the maximum to date. The abutments and gate-house construction had provided for only ten feet as a maximum, whereupon the abutments were raised 2 feet, and finally, in 1877, the whole gate-house was raised. The dam is built on a ledge

of red slate, which in some places turns to hard red sandstone. This dips at an angle of about 30 degrees with the horizontal, the low part of the seam being down-stream from the dam, so that the water, as it falls over, strikes the seams of the ledge in the best possible position for overturning the layers of rock, and for sending them on down-stream. The perpendicular fall of such a body of water for 30 feet would, naturally, very soon cut out a ledge of this description, and, added to this, came the effect of ice and logs going over, and striking on the bottom, constantly in about the same line across the river. In a case of this sort I have in mind, the hard ice going out in mid-winter, and falling only 18 feet, cut through an apron of 12-inch square timbers in a few hours, the sticks looking as if they had been pounded off with the back of an ax. Logs going over did mischief in another way. At the foot of any perpendicular fall of water there is what is called an undertow towards the dam. When the water strikes upon the rock below, with all the velocity due the height it fell, this velocity, or work stored up in the mass, must be absorbed in some way, and the volume of water made to pass off. No intelligent guidance being provided for it, the water dashes and flows about in any and in every direction, away from, primarily, not much more than towards the dam. Huge logs can be observed banging into the dam; then caught in another current and carried away from it; then again propelled against the dam, like a battering ram, and so on, frequently for a considerable length of time, before the log goes on down-stream. Be this as it may, in 1868, or when the Holyoke dam was nineteen years old, unpleasant rumors arose as to its security. There were depressions in the line of the crest, and sundry fishermen and others had seen thus and so. In point of fact, various examinations made soon after by adventurous parties who crawled through the dam, behind the sheet of water which in those days veiled the front face from inspection, revealed the unpleasant fact that the logs above named, striking the front face of the dam end on, must have got caught at times between the timbers of the dam, and the sheet of water then falling on them had apparently acted like a great power at the end of a huge crowbar to pry out the front face timbers. The ledge had also been washed out in front to a depth of 20 to 25 feet, and working in back under the dam, it had become undermined in places. This front lowest course of timbers, or the heel of the dam, had been very carefully built of three 15-inch square timbers all the way across the river, but when deprived



of the ledge beneath them, these large timbers were, of course, but imperceptibly better than any others would have been. A photograph now in the office of the Holyoke Water Power Company,* of the front face of the dam as it appeared in 1869, makes it look a good deal like a fort after a heavy bombardment. See Plate LIII.

The Apron of the Dam.

There was plainly no time to be lost, and during the years 1868, 1869 and 1870 was built the apron, down-stream from the dam of 1849, and shown with the dam in the cross-section on Plate LIV. As will be seen, its volume far exceeds that of the original dam. It is built of round logs laid up in perpendicular bins, 6 feet square in section, and was filled to the top with stone before it was covered in. The outside covering is of maple, beech and other hard wood—6-inch planks. The lower courses were built afloat, and in sections about 150 feet long. They were fitted, as well as it could be done by a plentiful use of the sounding-rod, to the irregularly-shaped bottom, then sunk by loading with stone. That part of the apron which is above the water level of the pool below the dam was then built as a continuous structure, on top of these lower sections. The lower sections not fitting very closely together, left a series of submerged culverts through the apron, and it was through these culverts that the water spouted out, with great velocity, at a later date, whenever there was any break in the covering of the original dam, as will be spoken of later. In loading the apron with stones, some of them weighing 4 and 5 tons, the stones were brought down the river in scows, and in process of transfer many were dropped into the water, which then struck the back of the dam. Indeed it was no extraordinary performance once in a while to spill a whole scow-load upon the old dam. Once out of sight, these stones were soon out of mind, and so remained until discovered by the divers in 1885. The whole cost of this apron is variously given as $263 000 to $350 000. The effect of the apron has been to prevent further undermining next the heel of the dam, also to support the dam where it was undermined. On the other hand, it speedily caused a new pool to be excavated below the dam, which is again 20 to 25 feet deep at the deepest parts.

During construction of the apron, considerable stone was also filled

* The Hadley Falls Company failed in 1857, and was succeeded by the Holyoke Water Power Company, the present owners, in 1859.

into the old dam. This was done in a rather irregular manner, however, as appeared during the repairs of 1885. Some of the bins were not filled at all, some were filled more than others. As near as I could judge, a slope of 45 degrees from the crest, up-river, might represent the average fill. The whole work was done without the aid of divers to clear for or to set the foundation courses, and was what may be classed as first-class log-driver's work. It was done while the late S. S. Chase, F. Am. Soc. C. E. (died May 29th, 1873) was agent of the Holyoke Water Power Company, and Mr. T. A. Ricker was the foreman in charge.

1870 to 1879.

In this way the dam did its duty until 1879, say ten years more, the crest having, however, been leveled up to the lawful height of the dam, as fixed by the original masonry bench mark, in 1875. This was done by spiking on a new crest timber, and planking down the two slopes up-stream and down-stream with wedge-shape plank, thus making a level crest, but piling on a further thickness of timber at the crest. Ten years later the removal of the crest and of the up-stream portion of these wedge-shaped planks, made no little extra work for the repairs of 1885.

Breaks and Cribs, 1879 to 1885.

One fine morning in 1879 there appeared a very well-defined whirlpool on the surface of the water just above the crest of the dam, and examination soon showed a break through the plank-covering at that point. This and subsequent breaks were repaired by means of cribs sunk so as to inclose the break in the plank-covering of the dam. These cribs were like a box without top or bottom, the under-side of the box cut off on a bevel, which, set on the back of the dam, would bring the upper side horizontal. During the succeeding six years these cribs went through a course of development towards perfection, and increased in size commensurate with the demands of breaks of increasing size, as will presently appear. At one time there was a fleet of six such cribs of various sizes in plan, and of various heights (to fit on the back of the dam at various distances up-stream from the crest), afloat in the pond. The largest crib built is shown on Plate LV, and its construction will need no further explanation.

The break of 1879 was located as shown on the diagram of Plate LVI, and was repaired without especial incident, except such as would

naturally accompany a new experience of that sort. In 1881 there were two more breaks, likewise shown on Plate LVI, which were repaired that year. The presiding genius was a river-driver, who put on also the little patch near the north end of the dam. I may as well mention here, that in 1885 we laid dry this little patch and went under it, inside of the dam. Not finding any of the planks gone underneath the patch, it became interesting to know what that patch had been put on for; but this I have never found out, and must leave it undetermined and a trade secret, as it no doubt was meant to be, by one of the fraternity of river-drivers.

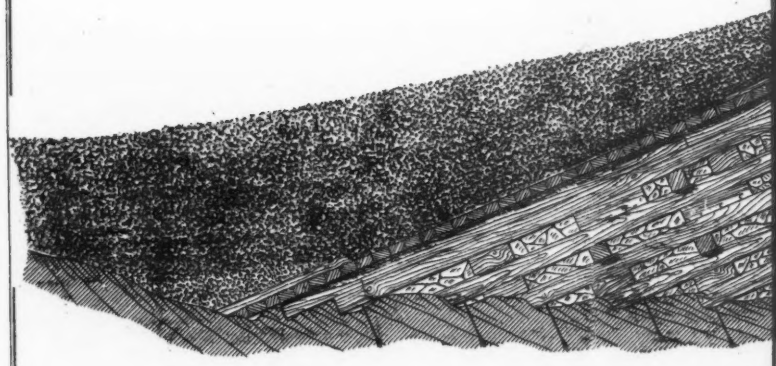
In 1882 the breaks of 1881 again broke through. My own connection with the works commenced in the winter of 1881–82. These two breaks were thoroughly repaired that year, the repairs running along until January or February, 1883, so that the crib from the last break repaired was removed through a channel sawed in the ice. One of the cribs was extended to reach to the crest, and the patch put on included a removal of 20 feet of the crest. The other crib was extended by sinking a sort of bay-window crib outside of the main crib, so as to take in a hole which broke through while we were at work on the original hole. In 1883 there were no breaks, but in 1884 they become worse than ever before. July 19th, 1884, a whirlpool appeared near the center of the dam, the mere central air-hole of which measured about 2 feet in diameter and was nigh 10 feet deep. The gate-keeper insisted that it had sucked in a row-boat which came drifting down the river, a story we always doubted; but in 1885 some pieces of a boat were picked up from out of the interior of the dam, which went far to corroborate the gate-keeper's thrilling tale. The crib used in 1882 was put around the whirlpool, when it was found that the hole had grown meantime, and had extended beyond the capacity of a 20 by 35-foot crib. 4 500 bushel bags of gravel—the gravel sewed up in the bags—dropped into this outside hole, failed to make any impression upon it; the intention having been, to temporarily close or partly close this hole by filling the bin or bins immediately beneath it; then to repair within the crib; then to remove the crib and repair the outside hole. Meantime the supply of water was failing, and it became necessary to resort to other remedies. It was then resolved to build the large crib shown on Plate LV. This crib was commenced August 14th, and built stick by stick as fast as the lumber could be got from the saw-mill. There was no time to draw any

plans or do much designing. It was built for all the world as children build block-houses of play-blocks. It was finished August 28th. Its weight was about 100 tons, and 80 tons of stone were required to sink it on the dam. There having been no opportunity to prepare ways for launching it, it had to be moved as a heavy building is moved, and the shores of the river were soft ground for such work. On the 29th it was moved 14 feet; on the 30th, 4 feet; on the 31st, 4.5 feet; and the hollow island made of spruce timber was got afloat at 1.40 o'clock (*not* 13.40 o'clock) of September 2d. That day it was set on the dam, making 19 days from the time it was commenced until it was in place. To encourage other engineers engaged in similar work, I may say in passing, that these 19 days were lived through under the expressed displeasure and dissatisfaction of about all the people for whose very benefit this work was being done. To think back upon what was said at the time, we who did the work would think that we had been at least three months about it; but the record shows only 19 days, and I doubt if any one is left who does not now think that the whole operation was highly commendable in all who took any part in it.

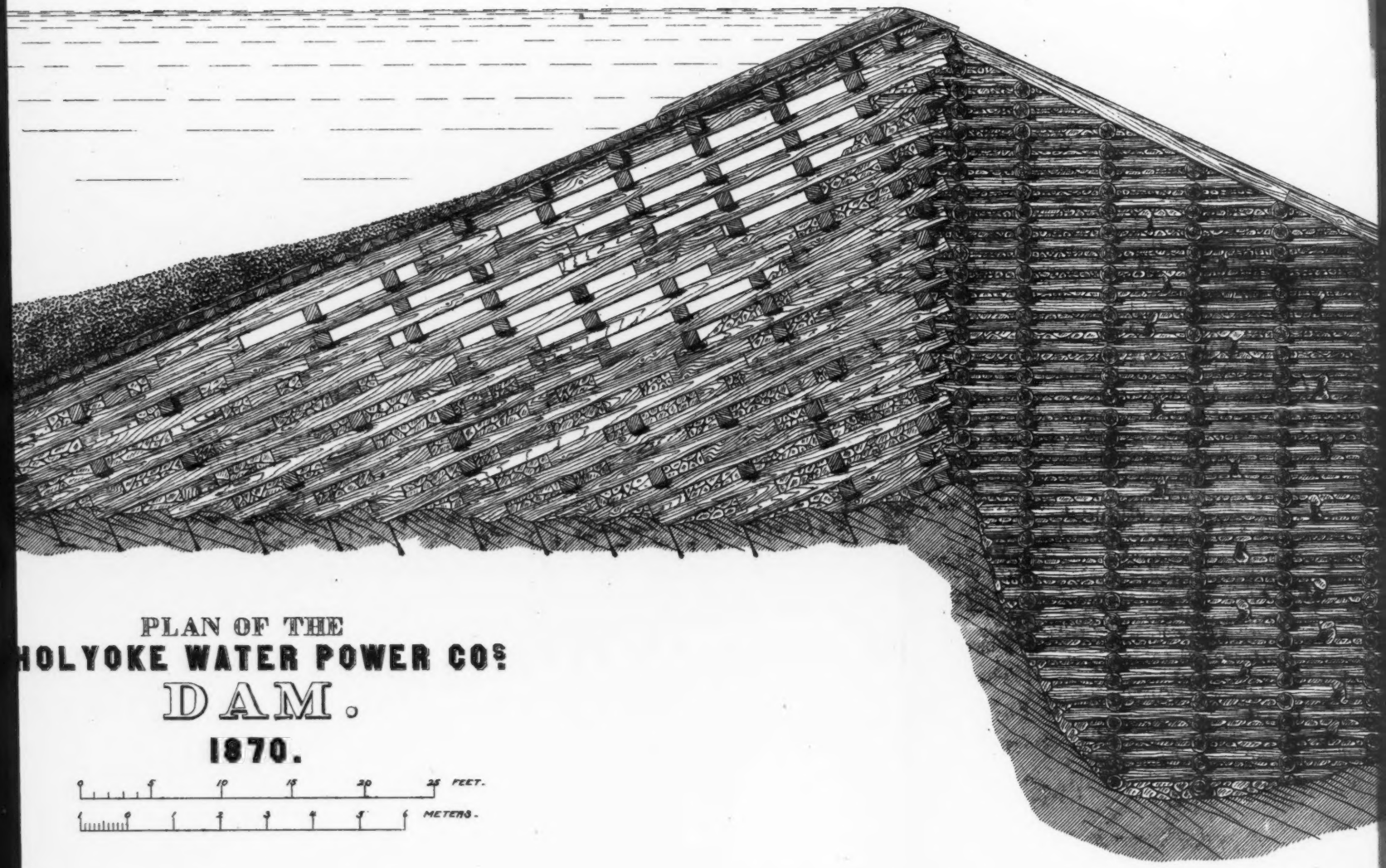
It may be well to speak, in this connection, concerning the details of the sinking of and operations within such a crib, as finally settled upon.

Work With and Within the Cribs.

The crib being hauled out into the stream was allowed to float down-stream, and so as to fence in the whirlpool, by carefully paying out on a strongly anchored line. At this time there would be a heavy pressure on the up-stream face of the crib, this face being much larger in area (owing to the slope of the dam) than the opposite down-stream face. Stones were then scowed out and dropped into the pockets of the crib at each end. When the crib took the ground it would do so by a sudden movement, and, owing to the excess of pressure on the up-stream face, the crib would take the ground down-stream from a point vertically beneath it when afloat. It was therefore necessary to allow for this, and to keep the crib 6 to 10 feet up-stream, while afloat, from where it was to stand on the dam. Sometimes timber-cleats were spiked to the crest of the dam to prevent the crib from getting too near the crest; for once aground, and not in the right place, the unloading and moving of such a craft would have been difficult, time-taking and expensive. If the break was near the crest, so that the crib could stand on the plank-



HOLYOK



PLAN OF THE

HOLYOKE WATER POWER CO.S

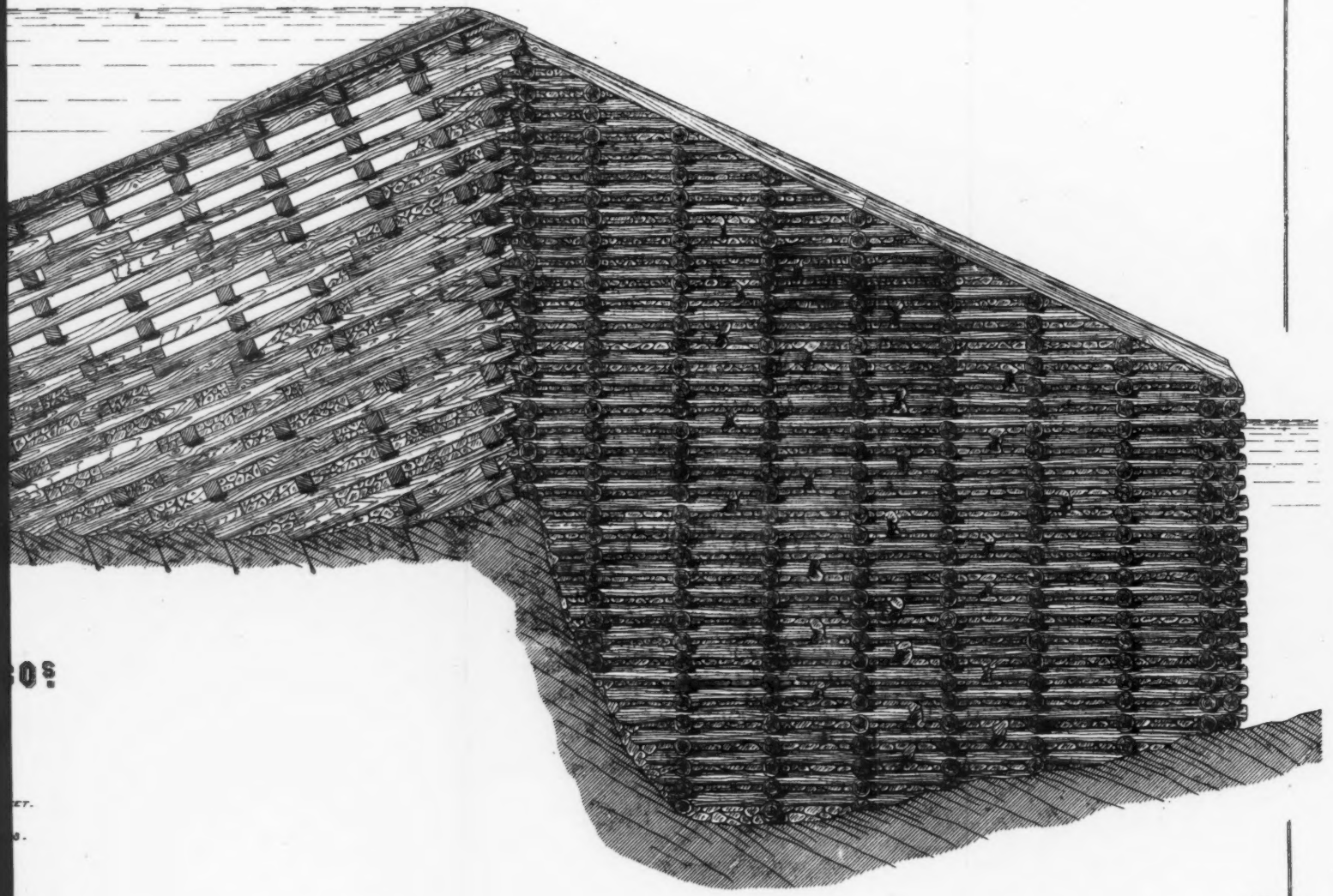
DAM.

1870.

0 5 10 15 20 25 FEET.

0 1 2 3 4 5 METERS.

PLATE LIV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM



covering of the dam, the subsequent work was comparatively easy; but if the crib had to land partly or wholly on the gravel and boulders covering the dam up to 40 or more feet upstream from the crest, there remained considerable work yet to do to carry the crib, sometimes nigh 15 feet through this deposit, to a junction with the dam beneath. In 1885 I tried the water-jet to effect this, but with only partial success, for the reason that some of the intervening deposit consisted of heavy 2, 3 and 4 ton boulders, water-logged logs, and similar heavy material. The orthodox way, and the only way I yet know of, that is feasible, was to calmly proceed to drive sheet piling all about the crib. Then, when the current under the crib had become sufficiently accelerated and concentrated, to drive out from underneath the edge of the crib any boulder that might have lodged there, the crib would settle; the sheet-piling plank already driven, being prevented from settling with the crib, would strip off, and proceed to lay themselves fan-shape upon the surface of the water, whence most of them could be picked up and driven again. In this way the sheet piling for the 1885 crib, which is the one sunk through a thicker mass of deposit than any of the others, was driven six times before the crib could be brought to a good bearing on the dam. The crib once on the dam, the joint between the sheet piling and the dam was made tight by dumping in bags of gravel. These were second-hand bags of gunny or other coarse cloth, costing usually about 5 cents each. The gravel was sewed up in them and the bags dumped in, some loose gravel being added from time to time. Clay is generally used in the same manner, but for what reason I have never been able to discover. It is more difficult to handle and melts out of the bags to a material extent on being thrown into the water. I have always used clean gravel and strongly recommend it. In the way described, a water-tight joint would gradually be made between the crib and the dam. This accomplished, the rest of the work would be comparatively easy. The water inside the crib would speedily run out through the hole in the dam, and the rest of the work would consist of ordinary dam repairs and of unloading the crib and floating it ashore.

Making of New Holes in Mending an Old One.

One great objection attendant upon this method of making the repairs, was the lodging of the crib (weighing, with its load of stone, up to 125 or 150 tons when half empty of water) on top of a boulder

or hard log. This would have a tendency to break another hole through the dam, and in point of fact, in three cases out of the four under my charge, one or more such additional holes were punched through during the process of sinking the first crib. The dam being hollow, every hole through the covering would be followed by a large loss of water. In 1884 the hole finally measured about 60 feet by 2 or 3 feet, which put under 10 to 15 feet head, will be found to pass no inconsiderable stream of water. The effect of the apron was to dam back this water fully 20 feet, or to within 10 feet of the crest of the dam, and the water escaped through the joints between the several sections of the foundation pieces of the apron, as above described. The water inside the dam could never be brought down lower than about grade 80 (top of the crest is 100), so that the contingency of a break below grade 80 was an ugly feature to look forward to.

But to resume concerning the operations of 1884. By the time the large crib, 40 feet by 45 feet, made to just take in the break in the dam when it was begun, had been set on the dam (the 20 by 35-foot crib having previously been removed) it was found that the hole had again grown, and reached beyond even this big crib. No lee-way could have been allowed in size of crib, because the pond would not have floated a larger crib than 40 feet by 45 feet, drawing 15 feet, nor would it have been otherwise advisable, as I now view the case. 40 feet by 45 feet will be found sufficiently unwieldy for ordinary work. To meet the emergency of the case, the 20 by 35-foot crib was therefore sunk alongside of the big crib, as shown on the diagram. This passed off without accident; the two cribs combined sufficed to cover the hole in the covering of the dam; and September 20th, noon, the big hole of 1884 was a thing of the past.

Autumn of 1884.

The proper course to pursue for the future became now a subject for most anxious consideration. The dam being all of the same age, there was no particular reason why the next hole, instead of measuring 60 by 4, should not measure 300 by 10, or any other dimensions (speaking after the manner of the integral calculus), within the limits of 1 017 by 92, the up-stream surface of the dam, and thus let out all the water of the river, and stop the mills, with an invested capital of $12 000 000, even if it did not destroy the whole dam. Again, those who had had a taste

of what it meant to fight the Connecticut River under the circumstances which have been described, had no particular liking towards a renewal of the contest. Personally I considered it a piece of good luck that we had been able to stop the 1884 break without first breaking in another large hole, and another, and another, and so on.

Some months after removing the 1884 cribs, there were indications of a large leak next below the patch of 1884, which did, in July, 1885, blossom out into the troublesome break of that year, in 28 feet of water and river deposit; but that was then in the undeveloped future. And I considered the covering of the dam in that condition, that I thought the usual 8 or 9 feet freshet in the approaching spring of the year would certainly cause incalculable disaster. All arguments in favor of proceeding to the construction of a stone dam, a work which would have required not less than three, and probably all of or more than four years, fell upon deaf ears, therefore, as far as I was concerned (from proper motives of policy they were also addressed to a person largely dumb); and with the support of the executive officers and of the directors of the company, preparations were immediately begun for a thorough strengthening of the old dam. But the discussions lasted long enough to lead to the designing of and experiments with the various forms of dams, to be built of stone, of which mention will be made later.

First Attempt at a Prevention of Future "Breaks."

The object sought to be accomplished was to prevent further breaks through the covering of the dam, and the project at first took the shape of endeavoring to sink cribs on the dam above the gravel line; to cut holes through the covering, dump in gravel, and wash it, or hydraulic it in, by letting water into the crib and upon the gravel. The idea was to give the dam a "subcutaneous injection of gravel." It was deemed advisable to make the attempt to do this work in the fall and winter of 1884, so as to have it done before the spring freshets. The big crib was therefore allowed to remain on the dam. Railroad tracks were built; a derrick and hoisting-engine provided; an Osgood dredge was built without the second chain or a dredge-bucket, to act as a floating derrick in handling the dump-buckets; 120 dump-buckets, and scows to float them, were built; electric lights provided, and Sunday, December 7th, the first 67 buckets of gravel were dumped into the dam. December 12th, 13th and 15th, 552 more buckets followed, when it became neces-

sary to abandon the work for the winter. What with the difficulty of keeping open a channel for the gravel scows, the freezing of the gravel in the buckets, and, worst of all, the accumulations of ice inside of the cribs, no progress could be made. The big crib was removed through a channel sawed through the ice, and the work came to a standstill until after the spring freshets. These fall to 2 feet on the dam at dates ranging from about June 1st to July 1st, which was not a pleasant outlook for parties anxious to commence work on a weak dam.

Winter of 1884–85—Studies for the Work to be Done.

Meantime, however, opportunity was offered for further careful study of the whole subject. A model of the dam and apron was made, $\frac{1}{48}$ full size, and embodying all that was known of the construction of the same at that date.

As this is written in an unconstrained, discoursive manner, I do not hesitate to speak at this point upon the great advantages to be derived by engineers from a study of models of a projected work. This is one of those things not taught in the academies, and many an engineer goes through his professional life unappreciative of, or disdaining the aid of, these most helpful, yet unassuming, instruments for stimulating his inventive powers. And yet we have very high and, in the profession, ancient authority for such methods. John Smeaton, the builder of the Eddystone light-house, was the first man who, in English-speaking countries, called himself a civil engineer. Before setting about the construction of the Eddystone light-house, he made, as is well known, a model, to scale, with his own hands, of the structure and of all the principal, if not of every stone in it. Many of the old masters in engineering were equally proficient in the use of tools, and believed in the teaching of models. It is to be hoped that the modern shop-practice form of education will enure to the benefit of the rising generation of civil engineers in this very manner. It may, indeed, give the model a social standing in every respect the equal of that now held by the drawing, and, this accomplished, its value in certain cases will be speedily seen to be far superior to that of the drawing. Without the education that comes from handling things—with all the work done under contract and by contractors—it has sometimes seemed to me that the profession was rapidly degenerating into the position of cloistered, closet students, or else of a high grade of "clerk of the works," and that none should more

favor the new education, which, as has been tersely put, "educates the whole boy, not half of him," than civil engineers. As far as my experience goes, I am free to admit that I have spent more time during the last six years in the carpenter-shop and on the works than I have at the desk or at the drawing-table, and a little more than the customary amount of this sort of experience would, I am convinced, benefit the work of any engineer.

It was while poring over the model of the dam spoken of, that my friend, Hamilton Smith, Jr., M. Am. Soc. C. E., suggested the idea of putting in a row of sheet piling, resting against a line of timbers of the dam, not perpendicularly, which would not have been practicable, but overhanging and at right angles to the covering of the dam, as was afterwards done; and, following up this idea, the whole scheme of the work was changed, from working inside of cribs, to the use of floating coffer-dams, which should reach to the crest of the dam, and lay dry a strip next the crest 20 feet wide and 100 feet long at a time. The coffers and end-piece finally used are shown on Plates LVII and LVIII, and the diagram on Plate LVI shows how the coffers and end-pieces were set on the dam.

Plan Adopted.

The whole plan as adopted, and in the main carried out, was as follows:

To set two coffers on the dam, making 100 feet of coffer, then shut off the ends, either by an end-piece, or by one of the abutments. Then set two more coffers outside of the forward end-piece, and another end-piece forward of these. Finally, take up the rear end-piece and two coffers, and set them forward of those last set, and so on. The end-pieces which were 20 feet wide would, in this way, alternately act as a water stop with one side and then with the other, according as each one came to be in the front and would next be left in the rear. To set them on the dam and make a water-tight joint, it was evident that the old method of sheet piling and bags could no longer be used, and it was determined to have divers clear off the dam, and make the joints by submarine carpentering. Once set, the water inside the coffers would speedily run out through the leaky dam; the covering for 20 feet down from the crest could then be stripped off, the sheet piling put in, gravel dumped either side of it, and washed down, or profusely puddled, until no more could be got in. The next step would be to restore the covering of the dam and go on to the next section.

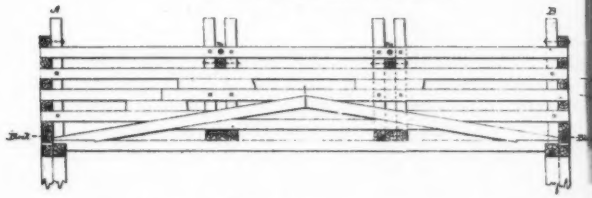
Beginning of the Work, May 29th, 1885.

With this general plan in view, and a profound appreciation of our ignorance of what was about to be encountered, both within and on the surface of the old dam, a diver was sent down May 29th, 1885, to clear the dam for the first coffer. It must be remembered here, that the only knowledge which had then been gained of the construction or condition of the dam, came from the limited views had of it and experience gained in course of the repairs with cribs. These frequently did not agree with old newspaper accounts, or with memory or tradition, so that considerable uncertainty existed on essential points. No great amount of stone was ever found inside the dam. This may now be readily explained by saying that the current through the break in the covering of the dam had washed them out. On the other hand there was always a good deal of gravel at the bottom of the river under the dam, which it is now plain, but was not then, had been deposited there during the gradual dieing out of the current, as the joints between the crib and dam had been made tight. No large stones were ever found on the dam, because, as is now clear, they had dropped through. Indeed, I feel strongly, that large stones of this sort dropped on the planking in 1868 and 1870, may have been the prime cause of several of the original breaks; and, if so, they would of course have been the very first thing to drop through, when the plank, on further weakening by age, finally and entirely gave way. But at the time, as said, the whole work was as yet in the nature of an untried experiment, with doubters of its success and opponents of the whole thing by the score; with active supporters of the executive officers of the company in their responsible and arduous position but few in number.

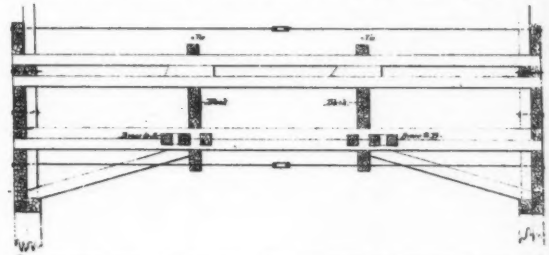
Clearing the Dam for the Coffers.

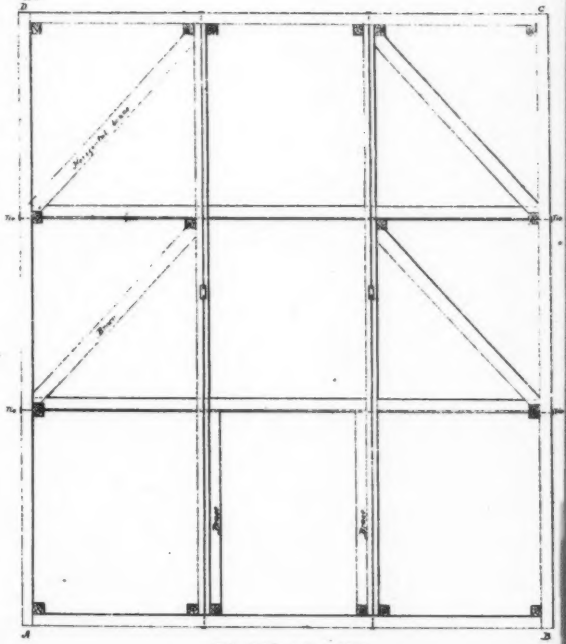
It soon became apparent that there was much more gravel debris and river deposit on the dam, than the soundings taken every 20 feet across, and at 5 feet distances up-stream, had indicated, or that the diver's capabilities in removing deposit, had been overrated. The plan had been to let him wash off the dam with a stream at 80 or 90 pounds pressure through an inch nozzle. But this alone would not do. A large and weighted hoe, worked from floats; cutting 9 by 9-inch holes through the covering of the dam, were tried in turn, without much success, though finally a small space, afterwards utilized for the site of end-piece No. 1

A-B END ELEVATION.



END SECTION, PARALLEL TO AND NEAREST A-B.

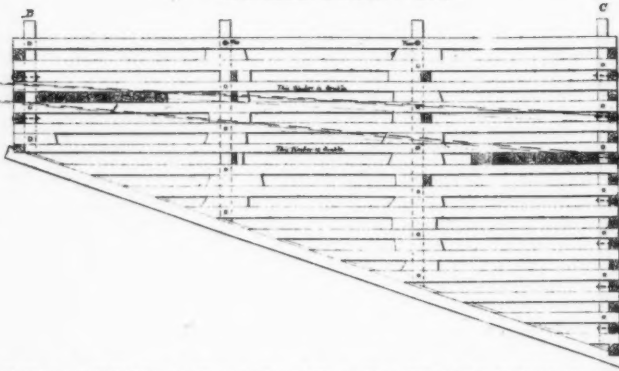




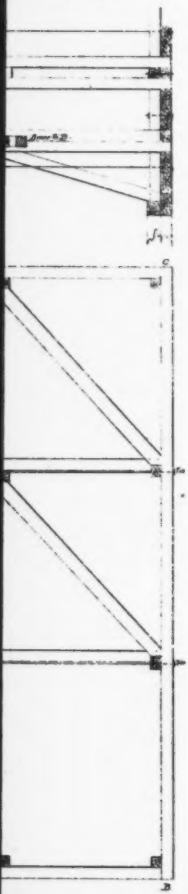
PLAN AT TOP.

ION.

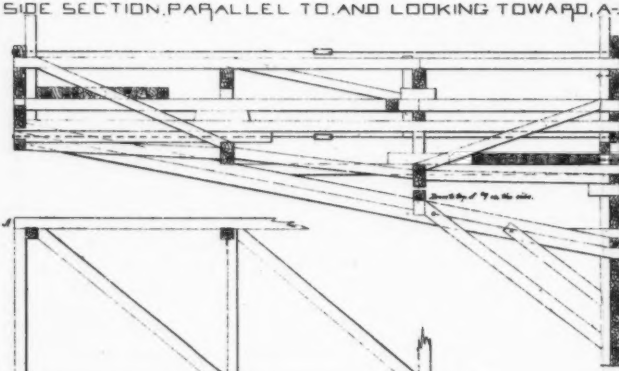
B-C. SIDE ELEVATION.

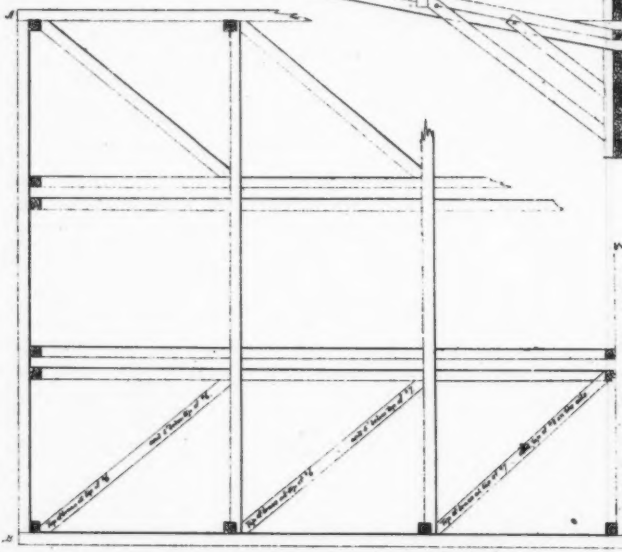


ND NEAREST A-B



SIDE SECTION, PARALLEL TO, AND LOOKING TOWARD, A-

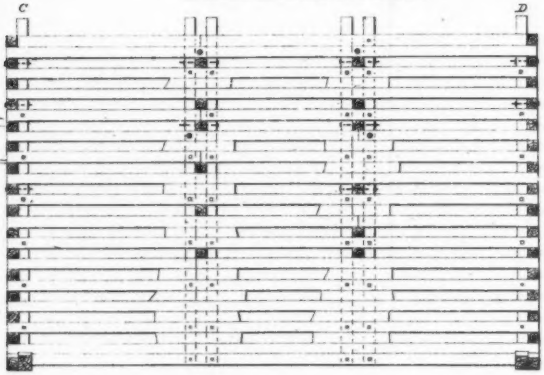




PART PLAN BELOW TIMBER NO. 6.

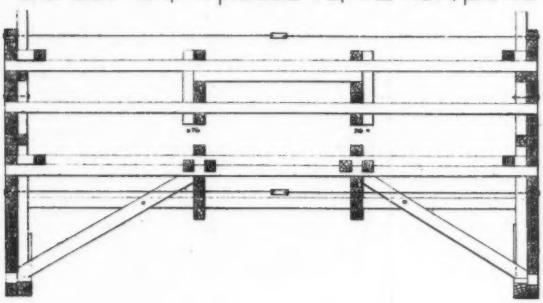
PLATE LV.
TRANS. AM. SOC. CIV. ENG'RS
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM

C-D. END ELEVATION.

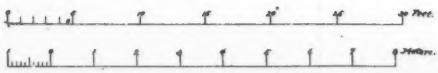


ARD, A-D.

END SECTION, PARALLEL TO, AND NEAREST C-D.



SKETCHES
TO SHOW SIDE AND END ELEVATIONS, SECTIONS, AND PLANS,
OF
THE BIG CRIB, USED IN 1884
TO COVER A HOLE IN THE DAM
DURING REPAIRS.
Holyoke, Mass. OUTSIDE PLANKING NOT SHOWN. December, 1886.



(indicated on the diagram), was cleared off in this way. To get an insight into the work about to be done, and to make a start, end-piece No. 1 was sunk as stated; the water let out of it, the planking of the dam removed. the stone found in the bins taken out by hand, and the sheet piling put in for a width of two bins. Plainly the success of the whole work depended on accelerating the work of the divers, for, from the start, it had been recognized that the whole work would have to be done in 4—at most 4½—months, or probably fail. And all efforts were now turned in that direction.

Submarine Road-Scraper.

The next experiment was with an ordinary road-scraper, hauled down the slope of the dam under guidance of a diver, by a hoisting-engine mounted on an anchored scow, and pulled back again by the same engine, by means of a line and snatch-block, the latter fastened to the crest of the dam. This plan worked fairly well, and two divers and crew (tenders and pumpers), with two men on the scow, cleared off 50 feet in five days, or, at that rate, 205 days for the whole dam; therefore, still too slow. This speed could, of course, have been doubled, by starting in another such crew, but the greatest objection came from the danger to the divers inherent to this method. The diver had to walk along behind the scraper and keep heaping up the material in a windrow at the end of his route. And it will bring home to the reader a realizing sense of the responsibility of the situation, when it is pointed out that, in the opinion of the engineer, there was constant danger that this extra weight would break through the dam, and in that event no doubt kill the diver, besides flooding the whole work. It was literally treading about on egg-shells—a constant exercise of all attainable caution, and yet striving to push on the work. The freshet in the spring of 1885 had been only 6½ feet on the dam, instead of 9 feet or more, as usual, and to that extent the dam had again been tried, but it was not to be thoroughly trusted in any portion of the covering. And it was well that it was not trusted. Later on, the divers were obliged several times to floor over portions of the dam before they dared to walk or roll stones about on it. Especially did it become necessary to board over leaks, which sucked in the air-hose and were otherwise annoying and dangerous.

Dredge to Clean the Dam.

The plan decided on was to convert the Osgood floating derrick into a very small (half-yard) clam-shell dredge, then let both (finally three divers) play on the gravel until a windrow had been formed, then let the dredge remove it. To save time, the dredge had orders to work early in the morning, noon-times and nights, and under no consideration to let the bucket come down hard. This made the work of the divers comparatively safe, for they heaped up the material ahead of them but little, and where the dredge had been at work it was reasonable to assume that a 30 to 40-pound diver could walk about. This plan proved very successful and completed the work. On the diagram Plate LVI, will be found the dates when the divers commenced and finished cleaning the different sections; when the road-scraper and when the dredge commenced; when the several end-pieces and coffers were set, the sections laid dry, gravel filling put in, and other information. The dredge built to swing buckets of gravel into the dam, in point of fact never swung a bucket in 1885; but as a dust-pan for the divers' sweeping she became "worth her weight in gold," as they put it; besides which, she could in fifteen minutes be stripped of her bucket and serve as a floating derrick to hoist up big stones, chained on by the divers, or to set the coffers, or to pull them off again. As she did her part to save the whole concern from shipwreck, she was not inappropriately named the Grace Darling, and served faithfully to the end. Three divers to operate three nozzles and fire streams, and the dredge, finally cleared 120 feet of dam in about four days, sometimes removing from that length of dam, five or six scow-loads of big stone. The divers also made tight all the joints between the coffers and end-pieces, and between these and the dam, and generally were indispensable for a rapid, or for a practicable, prosecution of the work.

Loss of Two Divers.

While on this subject, something more may be said as to divers and their work. Barring sprains and bruises, also one leg broken, the loss of two divers were the only accidents among 125 men, working over four months on this somewhat hazardous undertaking. The first diver lost, went over the dam, Monday, June 8th. Several weeks later, and after they had got away, his mates confessed that he had drunk himself into a comatose condition the night before, and had been remonstrated with,

not to go to work that morning, as being not yet over his drunk. And this much being stated, no further explanation is necessary. These circumstances did not, however, prevent his mates from going about with a hang-dog air, and as though the accident had been the fault of the work, too dangerous, and all that, and they actually succeeded in stopping the whole work for about a day and a half. The discharge of the whole gang and a commencement with an entirely new set was necessary to put things to rights again. In going over the dam, the diver was stopped on the apron by his life line, though the air-hose coupling pulled out. Afterwards, through some bungling, he was allowed to slide into the pool at the foot of the apron. He was got ashore in just five minutes from the time the hose parted, with a physician, summoned by telephone, there to receive him, but the man was then dead.

GROSS NEGLIGENCE IN THE MANNER OF CONSTRUCTING DIVERS' ARMOR.

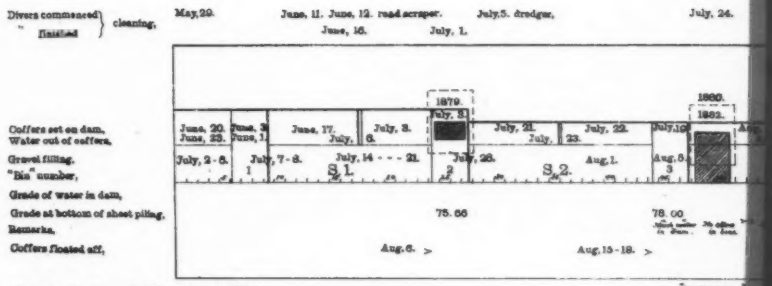
I will now state the details of another accident to a diver, and am thus enabled, by the contrast of results, to call the attention of the profession to a gross piece of negligence, as I have long viewed it, practiced by makers of divers' gear in this country. But the first-named accident enabled me to nullify such imperfection of armor, at least within the range of my own influence, after I had been faithfully working to that end for nigh twenty years. October 27th, 1885, John P. Mitchell, who had worked longest on the Holyoke dam, was down in 90 feet of water in the hold of a vessel sunk off Baker's Island, Salem Harbor, Mass., when a portion of the air-chamber of the air-pump blew out without attracting the attention of those on the divers' schooner. This naturally deprived Mitchell of all supply of air. He signalled for more air twice (this is done on the air-hose), but his signals were not noticed for some reason unknown. He felt a bursting pressure about his head (I felt a little of this myself in an experiment to be detailed later), then lost all consciousness. On the other hand, the tender not hearing from his diver for some time, signaled him twice on the life line to learn whether he was all right, and getting no response Mitchell was hauled up. He was entirely senseless when laid on deck, but came to after a little while, and the next day was apparently none the worse for his experience of the previous day. To explain the contrast, it is necessary to call attention to the one radical defect in all divers' gear as made in this country, which is the absence of a check-valve next the helmet, where

the air-hose enters. This struck me as a piece of negligence, or what should be considered negligence, the first time I saw a diver's gear, in 1866. I often spoke of it, and some eight or ten years later, read in a book, that in England a check-valve is always put in. Nevertheless, and in spite of lives being continually lost for the want of it, I could make no impression on divers and others about it. But after the death of the diver first above spoken of, and in telegraphing his loss, I added: "I insist on check valves being put on," which had the desired effect. The party furnishing divers immediately had them put on all his eight helmets; without such a check-valve Mitchell would certainly have been a dead man the moment the air chamber broke; and they have in other ways amply shown their value during the test of a season's service. Indeed, divers now lay immunity from certain accidents to them which should be credited elsewhere. Experiment has also shown that a diver could stay three minutes in 15 feet of water without any supply of air from the pump, and without material annoyance. He merely got tired of waiting, signaled for air, and went on with his work. Two and one-half minutes is all I wanted of it, however, sitting on deck with a watch in my hand. If now the profession will sternly set their faces against any diver going down on work under their charge unless the helmet be provided with the check-valve spoken of, I am satisfied that the great majority of losses of life among divers will have been prevented. And makers of diving helmets in this country should be made to understand that the making and offering for sale of a diver's helmet without a check valve on the air inlet is criminal malpractice. Another thing that should be insisted on is the use of a telephone between tender and diver.* The wires to be coiled about the hose to the pump, thence led to the tender; and the tender to wear a telephonic helmet after the manner of operators at the "Central Office." I believe that these improvements would lead to the more general employment of divers on engineering works, and this again would enure largely, I am convinced, to the benefit of many classes of such work.†

The second diver lost at Holyoke, in 1885, was Mr. Thos. W. Conklin, of New York, who had been a diver over forty years. (*Harper's Weekly* of August 22d, 1885, contains a fair portrait of Mr. Conklin.) His death is not chargeable to the regular work of preserving the dam

* See paper on Submarine Telephony, by Charles Ward Raymond, M. Am. Soc. C. E., Transactions of the Society, Vol. VII, No. 173, October, 1878.

† Since this was written, the Bell Telephone Company has devised a telephonic apparatus for the use of divers.


Divers commenced } cleaning, May, 29. June, 11. June, 12. road scraper. July, 5. dredger, July, 24.
" finished } June, 16. July, 1.
1879.
1880.
1882.
Coffers set on dam, June, 20. June, 23. June, 3 June, 1 June, 17. July, 3. July, 8. July, 21. July, 23. July, 22. July, 10
Water out of coffers, July, 6.
Gravel filling. July, 2 - 6. July, 7 - 8. July, 14 - - - 21. July, 26. Aug, 1. Aug, 5.
"Bis" number, 1 S 1. 2 S 2. 3
Grade of water in dam, 75. 66 78. 00
Grade at bottom of sheet piling,
Remarks,
Coffers floated off, Aug, 6. > Aug, 13 - 18. >

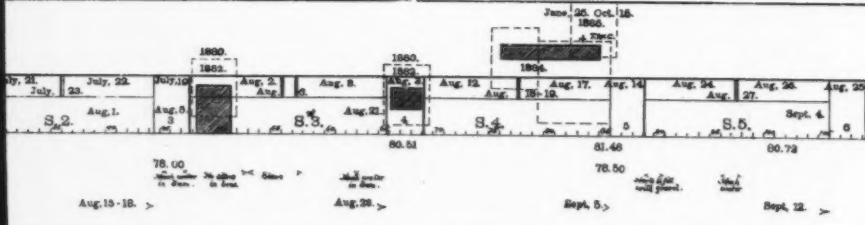
Remarks on front face of old dam as seen in 1869.

Timbers gone

Divers examination of apron in 1885.

. dredge, July, 24.

Aug. 24



Timbers gone. Timbers gone. Timbers gone.

Cave under apron. Front log gone.

DIAGRAM

Showing work done on dam in 1885.

Holyoke, Mass. January, 1886.

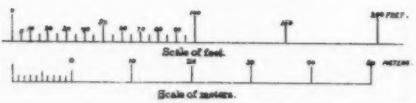
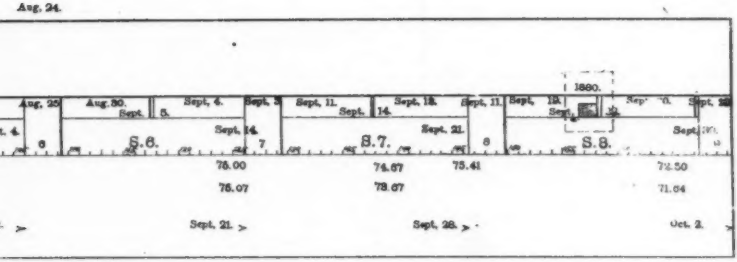


PLATE LVI.
TRANS. AM. SOC. CIV. ENG'RS
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM

Aug. 24.



Cave under apron.

here described, but occurred in working on the "crib" sunk in 1885, about the "break" of that year. After the crib had settled to a junction with the dam, the sheet piling having been driven six times, as above mentioned, it was thought worth while to attempt to save weight on the dam, by placing the bags of gravel by hand, rather than by dumping them in. The divers were instructed to lower themselves upon the covering of the dam, some 40 feet from the crib, on the solid patch of 1884, that afternoon; thence they were to have carefully felt their way towards the crib, and report. Mr. Conklin said he knew all about guarding himself against currents; he would crawl forward on his hands and knees, feeling for currents with one hand ahead of him. Notwithstanding these precautionary measures, the two divers, Conklin and Mitchell, rowed their scow straight out to the crib, in less than an hour after the above conversation, made fast to the crib, and immediately lowered themselves down a rope, the one directly into a hole in the dam, under 20 feet head of water, whose existence was not known, since which time nothing has been seen of him to this day. Mitchell, the other diver, was called up to see what was the matter with Mr. Conklin. He followed Conklin's line down, but checked himself on getting into the current, and was hauled up. By no power put on Conklin's lines in all conceivable directions, finally with a capstan, could they be made to yield in the slightest. The body was probably wedged far in among the timbers of the dam, and later search also failing to reach it, it is now buried in gravel near the exact center of the dam. Of course, it is easy to say that if the divers wanted to go at this examination by themselves, they should have felt first with a sounding-pole, or that they should have gone down a ladder, or done as was agreed upon but a short time previously. The use of a ladder, which seems so natural in the open air, is strangely fought shy of by divers, but should be insisted upon, in all cases of doubt.

Employment of Divers.

When it was first contemplated to employ divers, the two propositions, one to buy gear, and train some of our men to be divers, and the other, to contract for the furnishing of divers with gear, were fully discussed, and the second method was deemed the wisest and least liable to lead to loss of life or to consequent claims for damages. However that may have been, certain it is that none of our men would ever have been

lost in either of the ways in which the two divers met their death. No one who has ever worked on a dam like the Holyoke dam would think of purposely and needlessly crawling up to an opening in the flash-boards, with 3 feet of water passing through and over the dam, and thus be carried over, no matter how drunk he was. Nor would any one who had worked on any of the cribs ever have gone down alongside of one, except after making all possible preliminary examination. And such men would have heeded the advice and warnings, in each case given but a short time previously, against the very accidents that occurred. On the other hand, accidents and loss of life might have occurred in teaching the men to work in diver's armor. I leave the matter an open question for the future, though I think that any ordinarily intelligent workman should have little difficulty in learning to work at his trade under water; and with only a little time to spare, one may undertake to teach the art of both tending and diving to proper parties.

Coffers and End-Pieces.

The coffers and end-pieces were built on a platform wharf, and launched on ways into the water. When new, and loaded with stone, as shown in the drawing, a 50-foot coffer would float with the boarded side just about parallel to the surface of the water. Later on, when water-logged, they would float point down, until the stones were taken out, when they could again be made to float flat side up. The stone ballast was taken out, sometimes by the divers with the coffers afloat, sometimes by hand while the coffers were yet set on the dam. The first coffer and end-pieces built were 6 feet longer on the base than those shown in the drawings, and provided for a 4-foot freshet. It was afterwards deemed advisable to allow an increase of danger from freshets, by making the coffers narrower on the base and lower, but at the same time diminishing the danger from freshets, by being thereby enabled to do the whole work quicker. The two kinds of coffer and end-piece used, are shown on the diagram. As it afterwards turned out, the month of August, 1885, was the wettest August since 1856. It contained three freshets, including one of 4½ feet, which could barely be controlled by temporary flash-boards hastily put on. As one of the amenities of this sort of operations, it may be noted that 6 inches more of water would undoubtedly have flooded the whole work and the interior of the old dam. These coffers were a great success, and I again lay no small portion of this to

the use of models. A model of the coffers floated in a tub, showed their probable behavior in the mill-pond, which afterwards was perfectly realized. From being so evenly balanced when afloat, that either the open end, or top or bottom, would remain on top nearly equally well, the handling of the coffers and setting them on the dam, or taking them off again, became a matter of small concern. With the aid of the floating derrick, two coffers could readily be set on the dam in one day.

The end-pieces were, of course, more stable, and were simply floated in, hauled up and loaded. Two days' work of three divers would make all the joints tight, and everything was then ready to get the water out. One of the coffers had two gates, 4 feet square, cut in it, to supply the leakage of the inclosed portion of the dam. Without such gates, the water would fall a foot lower inside than out, and be apt to get the coffers out of line, before they were entirely loaded. Getting the water out was always an interesting operation. The forward end-piece had to be braced where it set on the crest of the dam, and this could not well be done until the water was down 2 or 3 feet. But everything could be got ready for it; then at a signal, the two gates would be hammered down, and within one hour from the signal, the slimy surface of the dam would be washed off with the diver's fire-stream hose, and eighty men would be at work inside, tearing up the old covering of the dam.

Unloading and moving the coffers was an anxious operation until it had been done once. The system adopted is shown on the photographic views. Timbers 12 by 12 inches were laid from the edge of the coffers, to the crest of the dam. On these were placed 3-inch planks, and the stone load of the coffers was then handed up, and piled on these planks. When all the stone had been thus got out (in some of the coffers from under 2 or 3 feet of water), the coffers, and section they inclosed, were allowed to fill with water, through the gates above mentioned. Then the stones were removed from off the plank, and generally used to set another pair of coffers further forward. Finally the plank and timbers were taken off. Most of the coffers remained on the dam when the work of removing them was at this stage, the planking over the joints, and to or against the end-pieces, being just sufficient to hold all in place. They were then hauled off by a capstan boat, or lifted off by the floating derrick. Sometimes they would roll off like huge porpoises, the moment the least pry was exerted to start them. The triangular shape of the coffers proved very advantageous for a floating coffer-dam, and

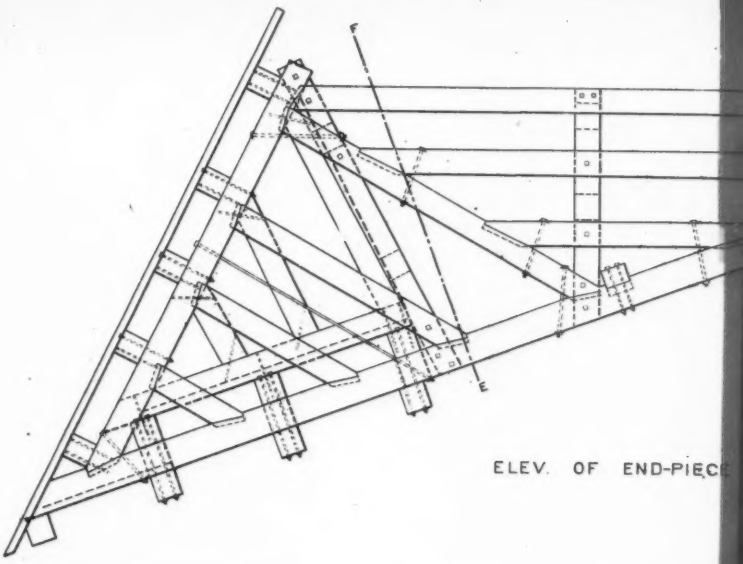
can be warmly recommended. Some of the coffers and end-pieces were used three times, and were good, apparently, for many more rounds of service.

Sheet-Piling.

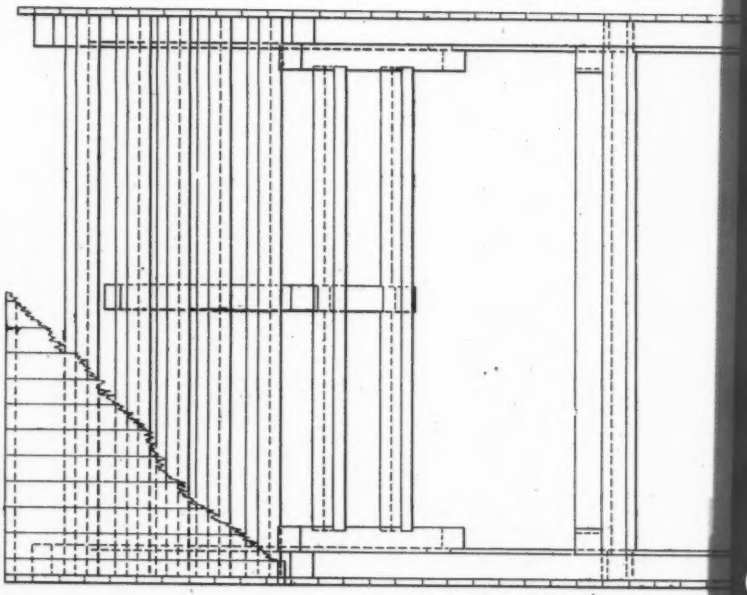
Without a model it is almost impossible to show clearly how a row of sheet-piling put against one face of one row of the bins, can make a tight water-stop throughout the crib-work of the dam. Suffice to say that it does. The bins were dug out, or the stone picked out by hand, as low as the water inside the dam would permit in every case, the men sometimes working in water up to their chins as they stooped down to pick up a stone with one hand. The diagram gives some measured grades of bottom of the sheet-piling. Throughout the dam this bottom was several feet below the old stone-filling, plainly to be recognized during this work, which had been put in in 1849. The sheet-piling was driven into this filling about a foot, all the plank reaching the width of one "bin," being driven at a time. But beyond this much driving, the planks were set as carefully by hand as any floor is laid, and were well braced against the opposite face of the "bin." Taken as a whole, and together with the frame-work of the dam that penetrates them, they constitute a close structure of 3-inch plank, some tongued and grooved, some only jointed, from one abutment to the other, and reaching down 25 to 28 feet below the crest of the dam.

Gravel Filling.

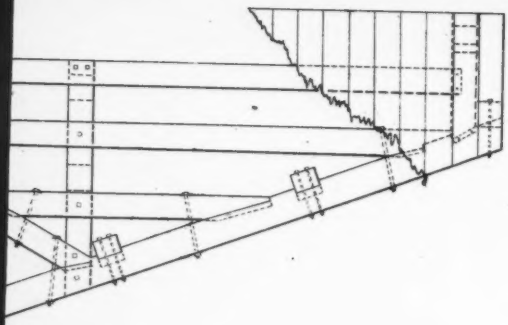
Each side of the sheet-piling is a mass of puddled gravel, measuring about 12 900 cubic yards altogether, being all that the dam would take when washed in with an ample supply of water. No part of the work gave less anxiety and more satisfaction than this, from the day it was started. And no part had been called in question to a greater extent, especially the "hydraulicing" feature of it, before the work was begun. Possibly these doubts expressed were the very instruments which caused the gravel service to be so well organized, and made it that part of the work which was constantly spurring the other parts to increased exertions and to increased speed. The gravel pit was about two miles up-river. A branch track to the Connecticut River Railroad, and a double track built on trestles next the same road, where it passes the head gate-house, furnished railroad connection. A double-drum hoisting-engine and derrick with wire-rope fall, served as a transfer from the cars to scows.



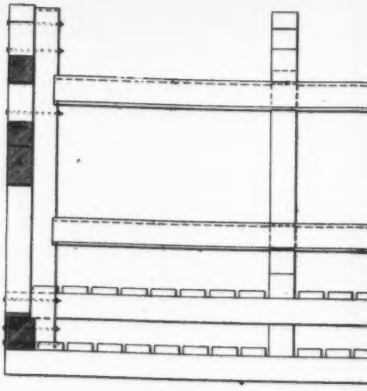
ELEV. OF END-PIECE



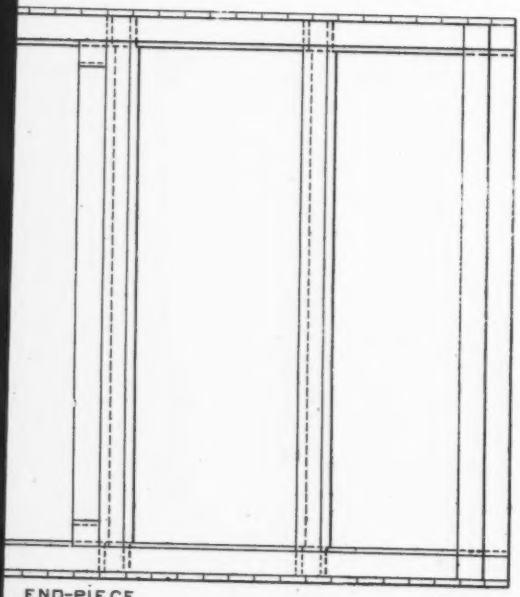
PLAN OF END-PIECE



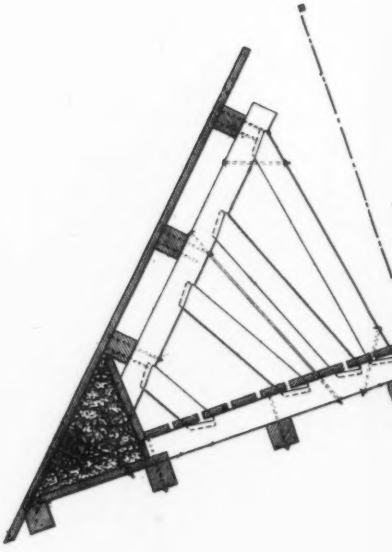
LEV. OF END-PIECE



SECTION ON E.F

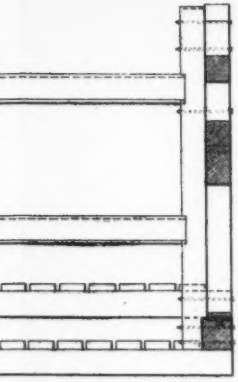


END-PIECE



SECTION OF COFFER

PLATE LVII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM



E F.

PLAN

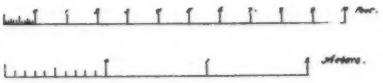
SHOWING CONSTRUCTION

OF

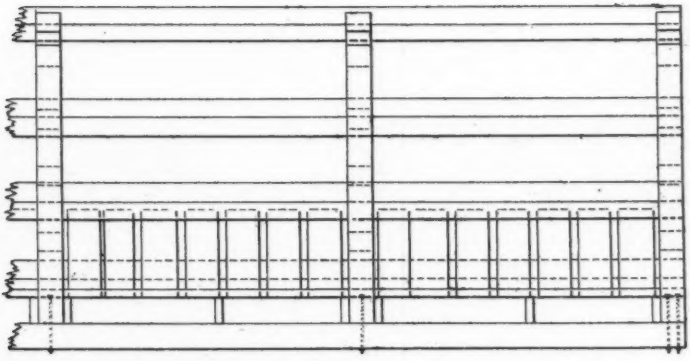
END-PIECE AND COFFER DAM

USED IN REPAIRS ON DAM AT HOLYOKE

SUMMER OF 1885



FER



FRONT ELEV. ON A.B.

Aug. 24th 1885

Float stages, 3 logs wide, served as a tow-path out to the work. A derrick on the work completed the machinery for handling or transporting the material. The gravel was loaded at the pit into dump buckets, 12 buckets just covering a flat-car. This meant 15 shovelers and a foreman. Two cars or 24 buckets made a train load. Three trains were constantly in service: one in the pit, one on the way, and one being unloaded by the shore derrick. This meant one engine-driver, fireman, and two brakemen. Three scows, holding 12 boxes each, constantly in service on the river: one being loaded, one on the way out, and one being unloaded by the derrick out on the work. This meant two men and two boys at hoisting engines, six men at shore derrick and scow, nine men hauling, baling and unloading scows, and one man to dump the buckets. In this way the gravel which was shoveled into a bucket in the pit was finally dumped from the same bucket where wanted in the dam. This required 108 dump buckets, or with an allowance for details to the hospital, 116 buckets. I give drawings showing one of these buckets. As an implement long in use in Holyoke, and by a process of practical evolution become a veritable "one-horse shay," no more likely to break in one part than in any other, let it not be passed by in disdain. They cost about $25 each, made of oak plank. See Plate LIX.

The controlling element in the line from the pit to the dam, as to speed, was the steam derrick on shore. As it had to pick up an empty bucket off the scow, then leave this on a car, be hooked to a full bucket and leave this on a scow, the extra hooking and unhooking of buckets put this derrick at a disadvantage with the derrick out on the work; which merely picked up a full bucket, swung it, had the bucket dumped, and retaining hold of it, swung it back on to the scow. The gravel service commenced July 2d, with 96 buckets put in that day; next day 159. By July 20th, 192 buckets had become the regular day's work, with one spurt of 204 buckets. By August 13th this had been increased to 240 buckets, and on the 23d, "Mose" beat the record with 264 buckets. But better work was yet to come. On giving them a "stent" of 328 buckets, August 29th, they had them all in by 4 P.M., upon which we kept right along (under extra pay) till 8 P.M., and put in 417 buckets that day. Finally, the record was beaten twice more with 372, and last with 395 buckets, up to 6 P.M., or in 10 hours; and 539 buckets in 13¾ hours, (39.2 buckets per hour) was the maximum day's work.

Put in at the rate of 360 buckets per day of 10 hours, it cost 32½ cents per cubic yard for wages (reckoning the bucket at 0.8 cubic yard) of which about 10 cents would be for railroad service, we furnishing our own brakemen and switch attendants. To this should be added cost of machinery required, or a percentage on same, and coal bill for two hoisting engines. Reckoning for the whole work of 1885, and including rainy days, windy days and other interruptions, the gravel went in at the rate of 254 buckets per 10 hours of days on which the gravel trains ran. Put in at the rate of 250 buckets per day of 10 hours, it would cost for wages 46.6 cents per cubic yard, with about 15 cents of this for railroad service.

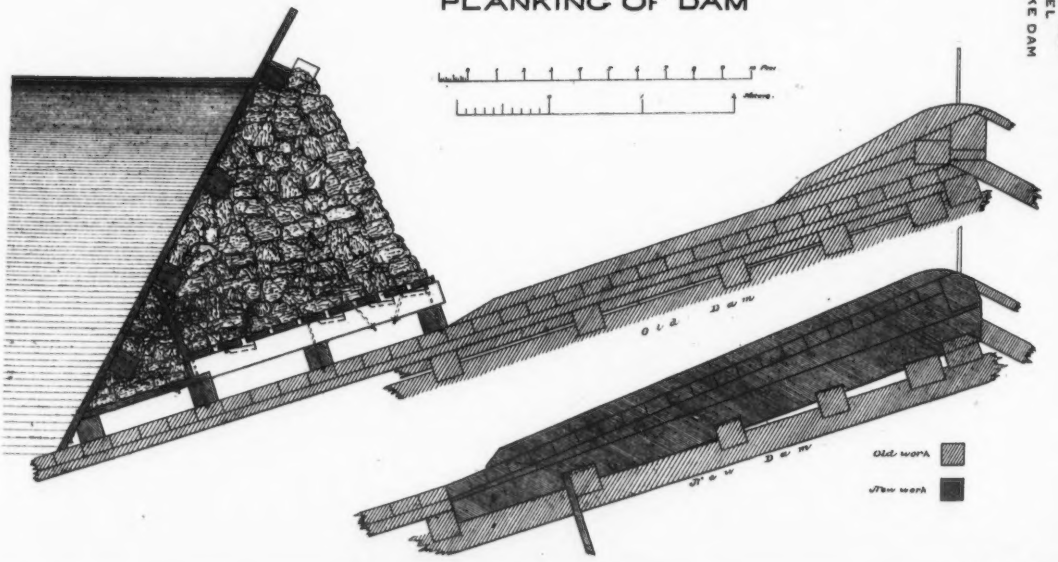
"HYDRAULICING."

It was important that the gravel should be made to reach as far into the dam as possible. The back of the dam being quite steep (about 2.9 on 1), it was evident that hydraulicing operations down the slope would be prosecuted under favorable circumstances.

A little reflection also showed that for purposes of washing a loose dump down hill, water from a state of rest would be nearly as good as water issuing forth with great velocity. We therefore used three lines of hose, tapped into the coffer-dam—an ample and cheap source of supply. Indeed, as it often seemed to the nigh-distracted chief engineer, the ready supply of water for hydraulicing purposes was the one advantage which could be set off against the many disadvantages appurtenant to working below the water level and out in the middle of the Connecticut River. Ordinarily the supply from the three lines of hose was supplemented, at the foot of the visible slope, within the coffer-dam, by a stream of water, let in, by pulling off a top plank somewhere; and along down the invisible slope, in the interior of the dam, and outside of the coffers, or directly beneath them, this joint supply of water for hydraulicing, was further supplemented, by the leakage of the dam, raining down upon the moving gravel mush, in perfect sheets. The old planks of the dam were water-worn at the edges, so that a spade could be stuck down through the seams in most any part of the dam. As a result of all this, the gravel and water poured into every crack and crevice, not to mention large void of the dam, in a very satisfactory manner. The amount put in, varied from 13 to 20 buckets per lineal foot of dam. With the 619 buckets put in in 1884, there were dumped and hydrauliced into the dam in all 18 121 buckets, which I estimate at

PLATE LVIII
TRANS. AM. SOC. CIV. ENGRS.
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM

PLAN
SHOWING
SECTION OF COFFER
AND OF
PLANKING OF DAM



Sept. 8th 1886

12 896.8 cubic yards. Assuming that the dam was filled 10 feet deep with stone in 1849, and estimating the filling of 1868-70 as equal to a slope up-stream from the crest of 45 degrees, which is the best estimate I could make, and taking out the volume of the timbers of the framing of the dam, I estimated from these data that it would take 11 300 cubic yards of gravel to fill all the voids. I am therefore satisfied that but little space devoid of gravel, stone or timber is now left within the dam. Such as there is, is of course, now full of water, which would in this way prevent any great pressure again coming upon the old planking, and would prevent what we have called a break. This, the primary object of the whole work, may therefore be considered to have been satisfactorily attained.

Any Further "Breaks" Impossible, or of No Consequence.

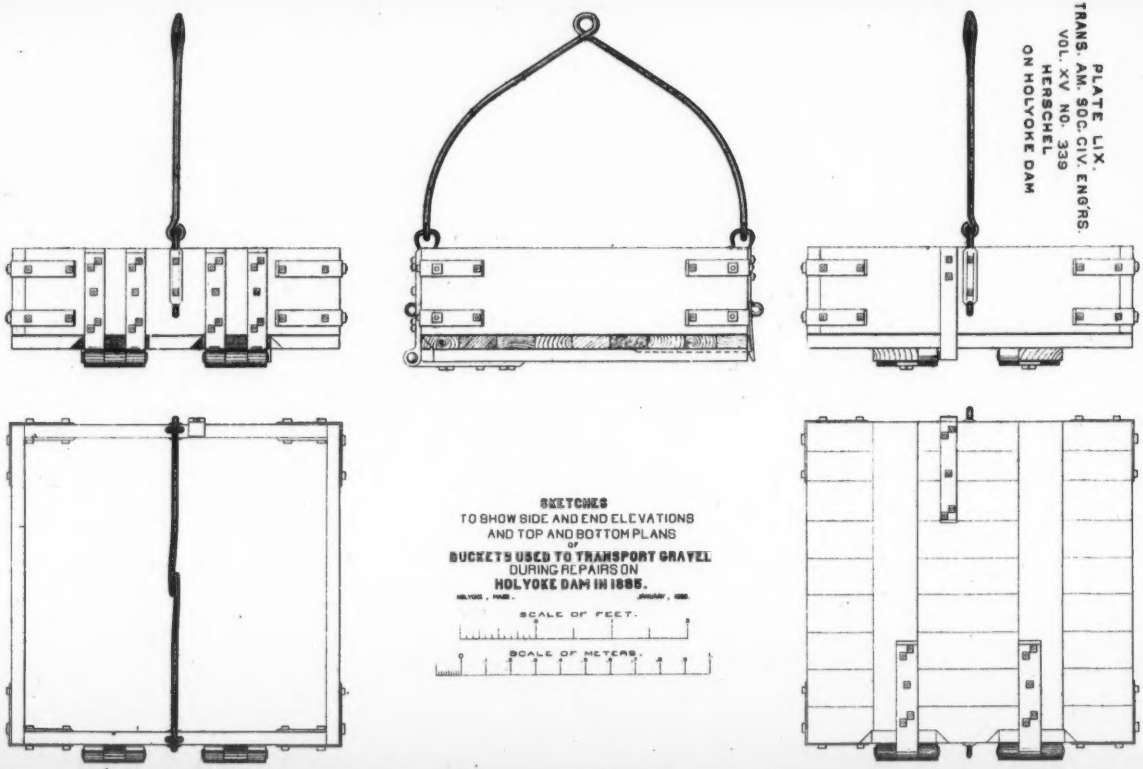
The hole in the covering, through which the diver, Mr. Conklin, was drawn into the interior of the dam and killed, was not planked over. To avoid sinking another crib about it, it was plugged up by spiking plank after plank, let into this hole, first to the outside of the crib of 1885, then to the plank thus spiked on, and so on, until a solid timber plug, reaching, of course, above water, and measuring about 4 feet by 6 feet, had been thus constructed. Bags of gravel dumped in about this plug and the crib, soon made a water-tight joint, but as the water inside the dam could never be brought down below grade 80, the hole inside the crib had to be planked over by divers. After the work on the dam herein described was done, the gravel bags about the "plug" were removed by dredging, the plug was pulled to pieces again, and a diver went down a ladder and into this very hole. There was then no suction, naturally, and beyond being of historical interest, as far as this work was concerned, it was not different from any other shallow hole. As planking it over would have been attended with a good deal of difficulty, in removing and washing off more gravel, it was finally decided merely to fill it up with gravel and put about 10 feet of gravel on top of the dam at this point, which would bring the filling level with the general level of the bottom of the mill-pond next the dam, or would leave 15 feet of water above it. So far, therefore, from now fearing a break, a break if made artificially, would not now be of the slightest consequence. The frame-work or timbers of the dam would have to be pulled down stream and out "by the roots" before

the dam could move, even if all the plank covering below the tops of the sheet-piling put in were removed, or should in course of time, by a continuance of decay, resolve itself into vegetable mould.

Preservation of the Timbers of the Dam.

This leads me to speak in this place of a second advantage gained by the work of 1885. It was noted above, what confidence was had in 1849 that the fact of the dam being constantly under water would keep it from rotting. Unfortunately, wooden dams don't seem to act in that way. The 6-inch hemlock plank-covering of the Holyoke dam was rotten in places—the rot working upwards from the under side—until there was not so much as $\frac{1}{8}$ of an inch of sound veneer, I can call it nothing else, left on top. This was true in case of the covering where it consisted of a single thickness of plank. From the crest, and for 20 feet down the slope, for some occult reason the covering consisted of three layers of 6-inch plank, one on top of the other. The lowest layer was fitted in between the frames of the dam, making what we called a 6-inch furring between the bents, 6 feet apart, forming the bins. This layer was mostly of the consistency of, and looked as much as anything like, sauerkraut, as it comes out of the barrel. Besides being a useless mass of rotten wood, it evidently helped rot the top timbers of the frames of the dam. But in other parts, also, the top timbers of the frames of the dam were apt to be decayed at the corners, so as to make the solid remaining part a round stick, of a section equal to a circle inscribed in the original square cross-section. Two timbers or planks butted on such a timber would lose their support, and some of the breaks were of plank thus robbed of their end-support. All timbers showing any signs of decay, within 20 feet of the crest, were, in 1885, taken out and replaced by new ones. This comprised the top layer throughout; the two top layers for about 200 feet; and in a few cases the third layer also. It is not unlikely, however, that there are still some partly decayed timbers remaining within the dam. As the dam was, these would in a short time have become wholly decayed, and it is a question what will be the effect upon such timbers of encasing them in gravel constantly kept wet, or of putting them under water. Will the decay continue and spread further, or will it be arrested? I am not aware that there has been any precise information obtained upon this question. Be this as it may, the great majority of the tim-

PLATE LIX.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM



SKETCHES
TO SHOW SIDE AND END ELEVATIONS
AND TOP AND BOTTOM PLANS
OF
BUCKETS USED TO TRANSPORT GRAVEL
DURING REPAIRS ON
HOLYOKE DAM IN 1865.

SCALE OF FEET.

SCALE OF METERS.

bers of the dam were found in a remarkably good state of preservation, and these, I am confident, have been indefinitely preserved by the work of 1885. They have been put in precisely the same condition as a timber buried in the foundation course of a bridge pier or similar structure, of which we have examples in bridges built by the Romans in a perfect state of preservation after some two thousand years of service. And this preservation of the timbers of the dam, and the strengthening of any weak ones that may be among them, by encasing them in wet, solidly puddled gravel, constitutes an important, yet mere incidental, advantage secured during the process of preventing further breaks in the covering of the dam.

Stopping of Leakage.

A third such benefit secured, likewise incidental to the main object of the work, is the stopping of leakage through the dam. At date of writing (January, 1886) the water has not been off the crest of the dam since the repairs were completed; but it was off for half a day, and, skipping the night, for the following day, when the graveling was within about 100 feet of the further abutment. Comparing the leakage that day (which included water used for puddling, and leakage, whatever it was, if any, of the incomplete portion) with the leakage of the whole dam before the break of 1884, I estimated the former as equal to about one-tenth of the latter, a not despicable gain in permanent water power.

Replanking.

The replanking of the dam offers no peculiarities not sufficiently exhibited on the drawings. See Plate LVIII. The diagram, Plate LVI, shows the rate of progress of this and other parts of the work. It will be observed that, whereas the first half of the dam required a few days over three months time, the second half was finished in just one month. The increase in skill of each particular man on a work of this sort, and as the work progresses, is very marked; and triple the speed at the end, from that achieved at the beginning, I should consider generally attainable.

Electric Lights.

Arc lights proved of the greatest advantage for carrying on the work here described, and should be set up for all important hydraulic works. Such are always liable to have a leak break out in some part, which left

to itself, over-night, may mean disaster. Here, more than elsewhere, a stitch in time saves nine. The arc light enables such stitches to be taken and kept up until the leak is under control. The lights are also of advantage in pushing the work, especially in the autumn months. Only one whole night's work was done on the Holyoke dam in 1885, but work till 8 P.M. was the rule towards the end. A luncheon brought to the men on the work at six would be done for in fifteen minutes, and in the remaining hour and three-quarters a fair quarter-day's work was often accomplished. The work done after hours was always on that one of the several operations, constituting the whole work, which happened to be behind the others. Thus the whole line was made to keep step with the most forward parties. Moving of derricks and hoisting engines was done at noon-time, or likewise after six o'clock. And generally no pains were spared to make time. Men soon learned that it was more comfortable to buy oilskin suits than it was to get wet, and as those in charge saw no reason why people on shore, or on a river, should not work rainy days as well as sailors, the many days in July and August of 1885, on which it rained, were made to do a fair, if not their full, share of pushing on the work to a successful completion.

Closing of the Last Section.

From the beginning it was anticipated that as the work in the dam would progress, the leakage of the dam, or a portion of the lineal leakage, if I may coin the expression, would be dammed back, and caused to be concentrated finally in the last section to be closed. And several ingenious plans were under consideration for overcoming the expected difficulties of this last section, one or the other or several to be employed, according to the situation as it would present itself. It was a most agreeable surprise, therefore, when no difficulties at all were encountered. The last section and the last bent of the dam filled up with gravel as quietly as any grain-bin would with corn, and the sheet piling at no time had any material head of water against it. I do not undertake to give the true and correct explanation for this; the only one appearing plausible to me is, in the first place, that the last section of the dam leaked materially less than the others. Certain it is that the river on that side had filled in much more than on the other shore, or in the middle parts. On the other hand, it is known that the middle 200 feet of the dam had for the past five years been the worst part as

to leakage. If now it be supposed, secondarily, that this leakage was practically wholly stopped by the work as it progressed, it will explain the good behavior of the last section. What little water would find its way through the gravel slope or puddled embankment, inside the dam as it was built across, could also weep through the stone filling of 1849, although the sheet-piling foots into the old filling from 2 to 5 feet, and this has itself become thoroughly grouted with river silt and sand; and this much water could also leak through the sheet-piling, which makes no pretense to the tightness of good coopering. The above considerations lead me to expect, also, that the work done in 1885 will approximate more and more, as time goes on, to being absolutely water-tight.

Cost of the Work.

This cannot be precisely stated, for the reason that the expensive repairs of 1884, and of the break of 1885, were charged to the same account. My best estimate puts it at about $65 000, inclusive of cost of dredge, railroad tracks, boxes, scows, one hoisting engine, derricks, tools and plant generally.

The credit given in 1849 to A. C. McNary, as "foreman of mechanics." should be repeated for the work of 1881 to 1885 in behalf of Mr. Paul Hurlbut, of Holyoke. Mr. Paul Hill, of Billerica, also did efficient service at a critical time. And a general meed of praise should be accorded to the 100 or more French Canadians, "born with an ax in their hand," who did most of the carpenter and other intelligent work required.

The Lesson of 1849 to 1886 in the Construction of Wooden Dams.

Speaking of the lesson above cited as it presents itself to me, I should say: *First and foremost.* That a wooden dam should never be left hollow, nor should it be filled with stone. Let a row of sheet-piling be put in, in some proper position, then puddle in gravel. Gravel is water-tight, or soon becomes so; stone filling is not. Gravel will protect every timber it encases from rot forever; stone filling will permit decay, and so will the moist, foul air to be found in the interior of all hollow dams, Worst of all is a dam entirely hollow.

Secondly.—In crib work, two timbers should never be butted on top of another of the course next underneath. This would give each timber at the most a 6-inch bearing, and should the lower timber become decayed at the edges, or the butting timbers at the ends (both being places

where decay is worst), the strength of the bearing is speedily reduced to zero. It looks well on a drawing, or in new work, thus to butt timbers and the covering plank. But a great deal may be learned in pulling an old dam to pieces, and were I to design a new dam I should do neither.

Thirdly.—Don't make a masonry shelf on each abutment to take the place of the last bent or frame of the dam. When the dam settles, or compresses under its load, as it must, the shelf does not follow, and the result is a distortion of the framing of several bents next the abutments.

Fourthly.—The back of the dam needs to be guarded against such abuse as the dropping of 4-ton stones upon it, especially in the case of dams upon large rivers.

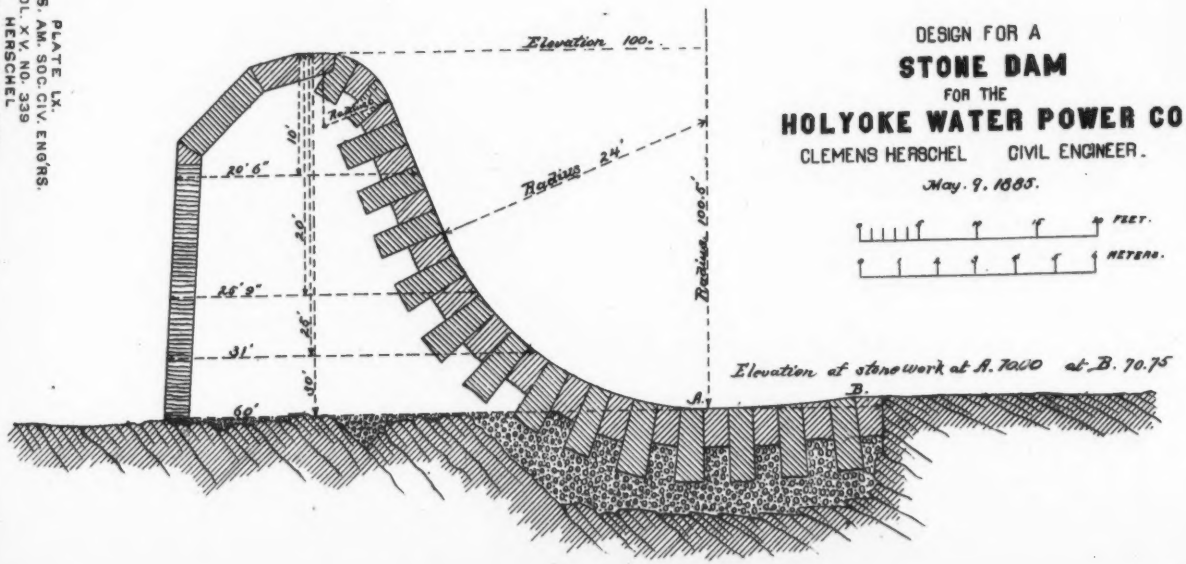
Fifthly.—The shape of a dam should be chosen with a view to preventing the excavation of large masses of the river bed, and the formation of a pool below the dam, in all cases. It is absolutely necessary to do this in the case of a gravel bottom; it should never be neglected in case of a soft rock bottom; it should be done in many cases of a granite or other hard-ledge bottom. A pool of water that cannot be laid dry is a source of danger in all hydraulic works, for the reason that one can never be certain as to what may or may not be taking place below the water surface; unless, indeed, periodical inspections be made in diver's armor, and even that would result in far less frequent examinations.

This brings me to a consideration of the shape which should be given dams, so as to protect the bottom of the river next down-stream, and as developed in the studies made in view of the possible construction of a stone dam at Holyoke. I will only say here, that the same general principles could, and should, as it seems to me, find application in the designing of wooden dams also.

Design for a Stone Dam at Holyoke.—See Plate LX.

In starting out upon this design, I made it a condition that the water, in falling over, should not again attack the river bottom, or should not cause the excavation at Holyoke of a pool No. 3; and that the dam should be amply able to hold a pressure of 15 feet over the crest. My first idea was to build a dam in steps. This shape has shown itself of good service for the reverse problem—that of breaking up the force of ocean waves. "Compel the water to walk upstairs," was said by a distinguished European engineer, "and you soon tire it out." However that may be for the upstairs transit, in going downstairs

PLATE LX.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM



DESIGN FOR A

STONE DAM

FOR THE

HOLYOKE WATER POWER CO.

CLEMENS HERSCHEL CIVIL ENGINEER.

May. 9. 1885.

FEET.

METERS.

Elevation of stone work at A. 70.00 at B. 70.75

water has a way of acquiring velocity in falling over the first riser from the top, and in virtue thereof, of skipping the second and most of the succeeding steps. Its progress becomes like a perpendicular fall in the case of one proportion of rise to tread, and becomes like unto boys sliding down the hand-rail of stairs, in the case of smaller risers and treads. In either case the bed of the stream at the foot of the stairs is very violently attacked.

The ogee form seemed to offer a solution of the problem, and several of these were next experimented with. Models were built on a scale of $\frac{1}{2}$ full size. Set up in an old canal-lock, a miniature 12-foot freshet could be poured over them to the great satisfaction and instruction of all concerned. The thing to be aimed at, was evidently to pass the water over the dam without allowing it to change its color. The moment it ceased to slide over, and commenced to fall, at any part of the transit, it would become white, or whitish. The exactly correct form to accomplish this, and no more, would be different for different depths upon the dam, greater depths requiring more base of dam, lesser depths jutting out less. But no harm is done in giving more base for the lesser depths, and some assumed depth may always be used in the computation of the proper down-stream curve of the crest and body of a dam, if the way by computation be preferred. The reverse incline at the foot of the dam was put there to destroy acquired velocity of the water, and to protect the bed of the river next down-stream from the dam. Too much lift, however, produces another fall below the lift; too little, on the other hand, destroys less acquired velocity than is feasible, and also erodes the bed of the river. I selected the slope shown, solely by experiment, and its final result is a sliding over of the stream of water until it is projected down-stream, apparently in a horizontal direction, and exactly parallel to the bed of the stream. The rise of the lift above a tangent to the lowest part of the apron, as finally adopted, was in the model $\frac{3}{4}$ inch. A lift of $1\frac{1}{4}$ inches had a materially different effect upon the sheet of water, 12 inches thick, passing over. Experiments made with the bed of the stream, represented by a box of pebbles, showed no undertow next the end of the lift. At this point the bank of pebbles remained intact, with the representation of a 12-foot freshet going over the dam.

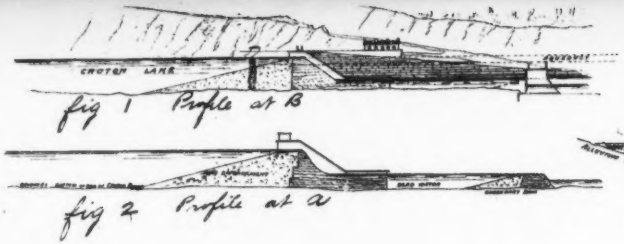
My attention has been called, since commencing this paper, to the cross-section of the dam at the outlet of Croton Lake, which is likewise

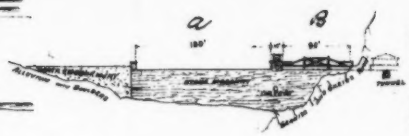
of an ogee form, only that the period of experimenting seems there to have been passed through with a model of full size, built on the site of the work itself; in other words, with the work itself. I was in entire ignorance of a dam with a curved front face in this country, at time of studying this question. As the Croton dam may not be widely known, a cross-section is here reproduced, Plate LXI. It will be observed that the reverse slope was added at a later day, and being constructed of wood, it had to be protected from decay by the secondary dam below. A waste weir permits the drawing off of the pool between the two. As this is a case of a gravel bottom, and this bottom is, moreover, several feet below the level of a horizontal continuation of the down-stream end of the lift, or reverse slope, the pool also serves as a protection to the bottom of the river below the dam. Another way to accomplish the same object would be, however, to make the down-stream end of the lift in line with the bottom of the river, and to secure or protect this bottom in an effective manner. The cross-section shown on Plate LX was especially designed for the situation at Holyoke, which, it will be remembered, has a river bottom of ledge, of a consistency varying from soft to hard rock, all the way across. There is a dam of an ogee shape in Spain, built by Sir James F. Bateman, the well-known English engineer. It may be found described in Moncrieff's "Irrigation in Southern Europe." This is the work (together with some more or less theoretical statements in various hand-books of hydraulic engineers), which first called my attention to this form of dam. As perfected by further studies, it clearly results in a fairly successful method of seeking "to convert, adapt, and apply the great sources of power in nature to the use and convenience of man." I believe that the engineer can never keep too closely to the pursuit of the high aim in these words set before him.

Description of the Photographic Views.

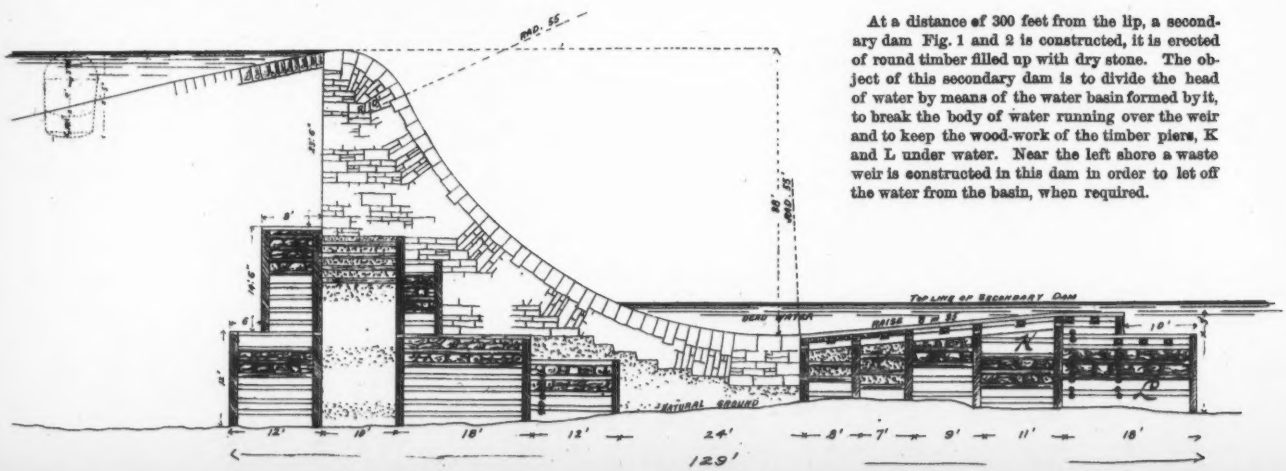
Plate LXII, July 10th, 1885.—In the foreground is the thirty-foot piece, between end-piece No. 1 and the Holyoke abutment, filled with gravel and being replanked. Section 1, just beyond end-piece No. 1, has been laid dry, and the crest-plates have been stripped off. Next beyond is the diver's boat, and abreast of it, the dredge, the capstan boat and a scow. In the distance some men are struggling to get the crib of

PLATE LXI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. NO. 339
HERSCHEL
ON HOLYOKE DAM





DAM AT OUTLET OF CROTON LAKE.



At a distance of 300 feet from the lip, a secondary dam Fig. 1 and 2 is constructed, it is erected of round timber filled up with dry stone. The object of this secondary dam is to divide the head of water by means of the water basin formed by it, to break the body of water running over the weir and to keep the wood-work of the timber piers, K and L under water. Near the left shore a waste weir is constructed in this dam in order to let off the water from the basin, when required.

1885 to penetrate the *debris* under its up-stream edge, by driving sheet-piling for the third or fourth time.

Plate LXIII, July 30th, 1885.—In the foreground is the 30-foot piece next the Holyoke abutment, replanked and iron crest and flash-board pins put back, timbers on crest and on the coffer, ready for unloading the coffer; same state of affairs in Section 1, with the long timbers just being put on. Gravel is being dumped into Section 2, and the diver's boat lies just beyond end-piece No. 3. Still struggling with the crib of 1885, this time with the pump-boat and the water-jet. The dredge at work with the clam-shell bucket.

Plate LXIV, August 5th, 1885.—In the foreground is the 30-foot piece next the Holyoke abutment, with 2 foot flash-boards on the crest, and water let over this piece, and into Section 1. In the foreground, men removing the timbers which had served to hold the stone ballast of the coffer abreast the 30-foot piece; and next beyond, the stone ballast of end-piece No. 1, and of the coffers of Section 1, may be seen supported by similar timbers. Next beyond is Section 2 being replanked, and beyond this is Section 3, still full of water, but nearly ready for closing the gates in the coffers. The water was got out of this section next day, August 6th. The boom of logs in the river is one that had broken away, up-river. Coming down upon the works they stopped the gravel filling for two days.

Plate LXV, September 1, 1885.—Showing Section 5, just after being stripped of the old plank and top course of timber, with new timber going on. In the foreground may be seen the sheet-piling of one "bin," the ends of the plank not yet sawed off even.

Plate LXVI, September 8th, 1885.—View from the shore. In the foreground the gravel train and steam derrick; loaded scow going out, and scow-load of empty buckets coming back. Two 50-foot coffers afloat, point down, abreast the outer scow; the crib of 1885, subdued and brought down into place, just beyond this scow, with the "plug" built in place, of 3-inch plank, on the side facing the shore. The dredge and the two divers' boats, hard at it, in the distance.

Plate LXVII, September 18th, 1885.—A view from South Hadley Falls abutment. End-piece No. 9 just run in, visible next the abutment. Then the diver's boat with the diver sitting on his iron ladder. Behind this boat a 50-foot coffer afloat, flat side up. Up-stream from this another 50-foot coffer afloat, point down. Gravel going into Section 7, and

the coffers of Section 6 being unloaded. The city of Holyoke in the background.

Plate LXVIII, September 18th, 1885.—View of Section 7. The old man on the extreme right, E. H. Humes, of Greenfield, helped build the dam of 1849, the apron of 1868–70, and worked on the dam the whole season of 1885. The row of sheet-piling is shown; gravel is going in, and the carpenters in replanking are crowding the gravel dumpers.

Plate LXIX, September 18th, 1885.—Practically the same as Plate LXVIII, but about an hour later. The three lines of hose have been shifted and now show under the gravel bucket.

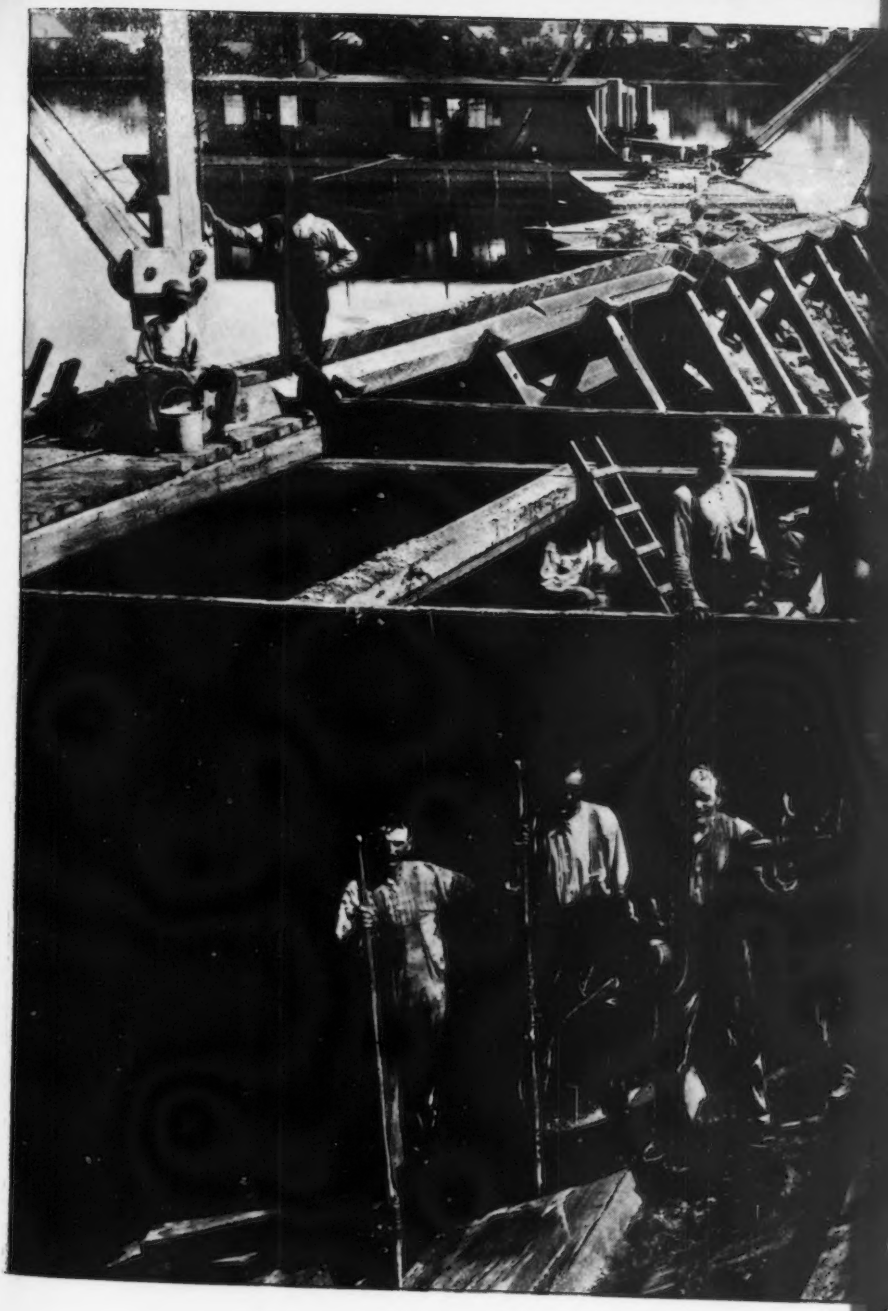


PLATE LXII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. No. 339.
HERSCHEL
ON HOLYOKE DAM.

PLATE LXIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. No. 339.
HERSCHEL
ON HOLYOKE DAM.

PLATE LXIV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. No. 339.
HERSCHEL
ON HOLYOKE DAM.

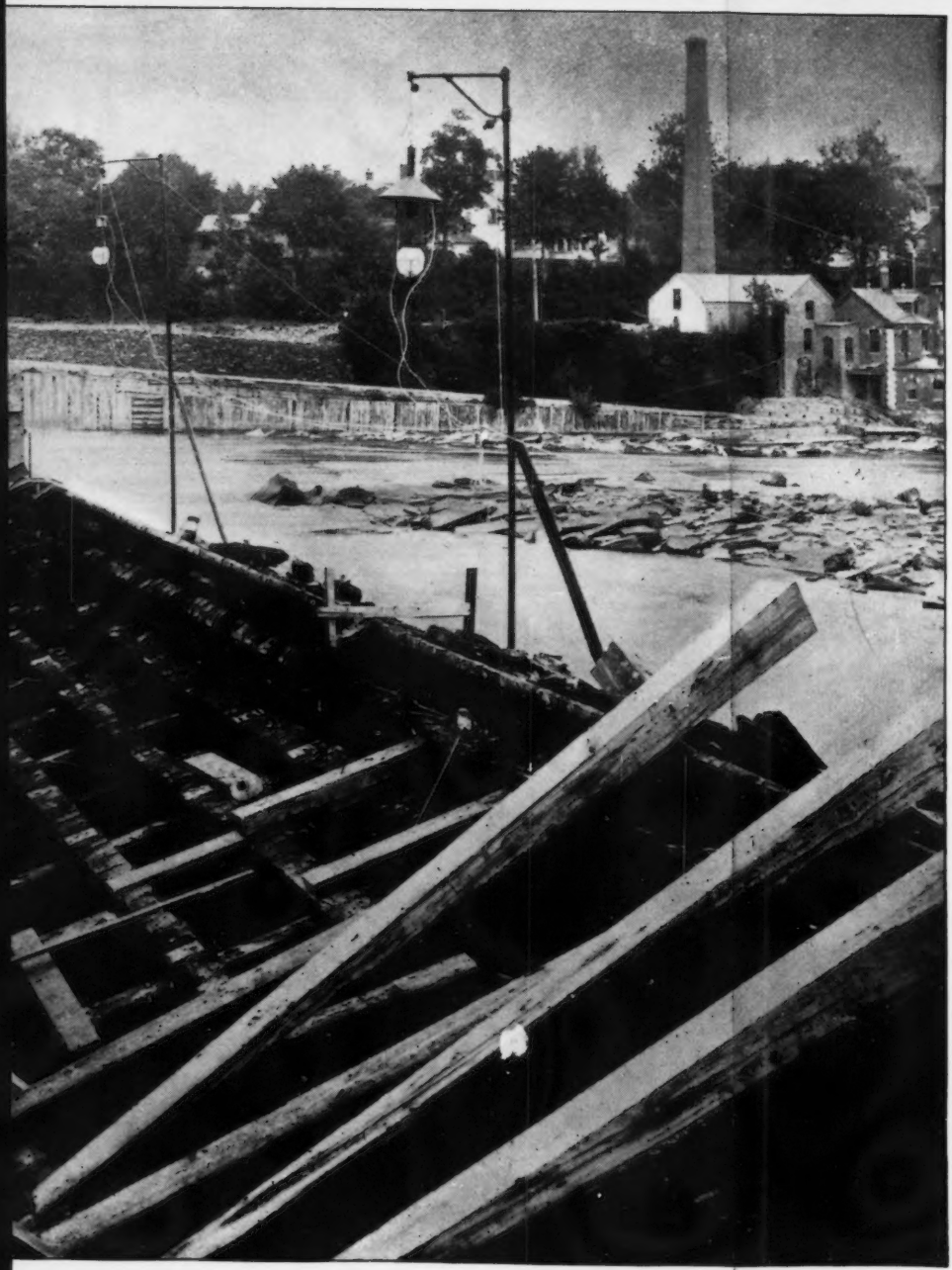
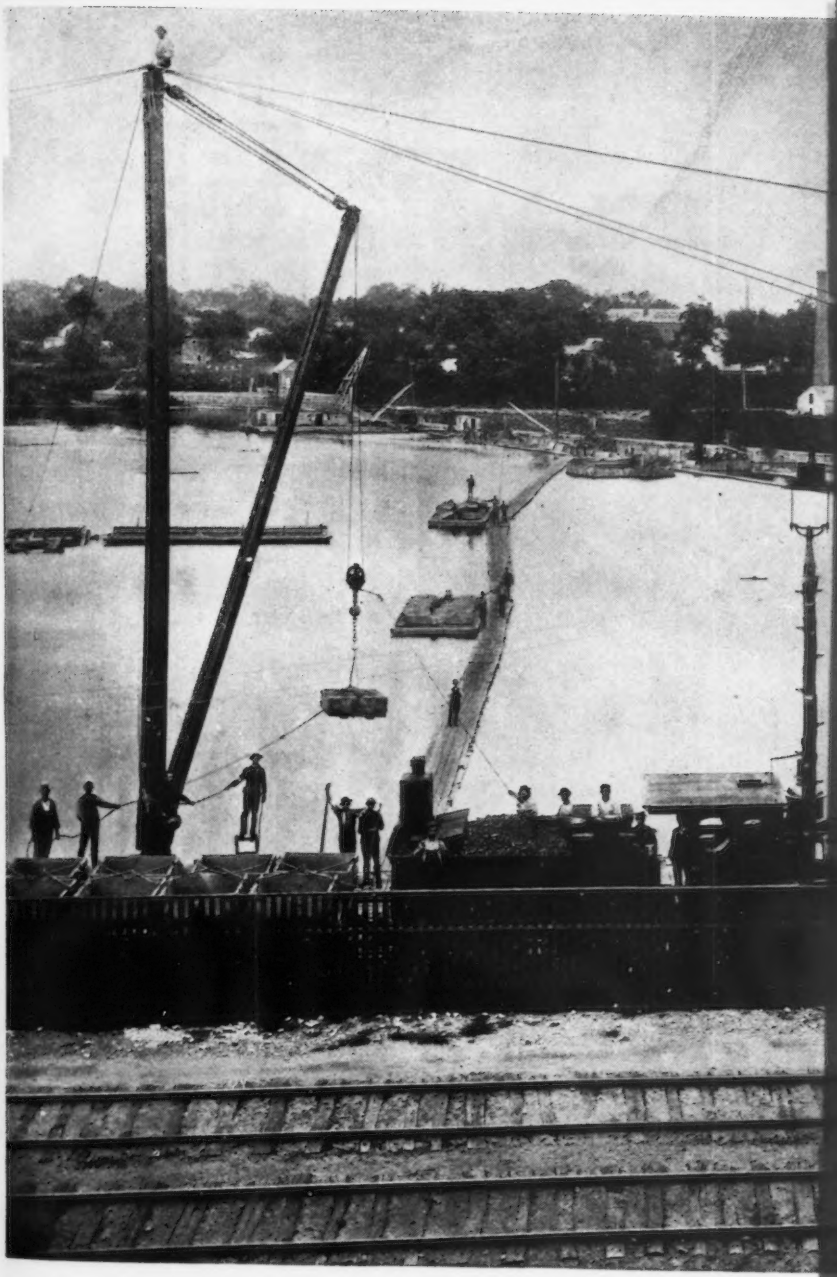


PLATE LXV.
TRANS. AM. SOC CIV. ENG'RS.
VOL. XV. No. 339.
HERSCHEL
ON HOLYOKE DAM.



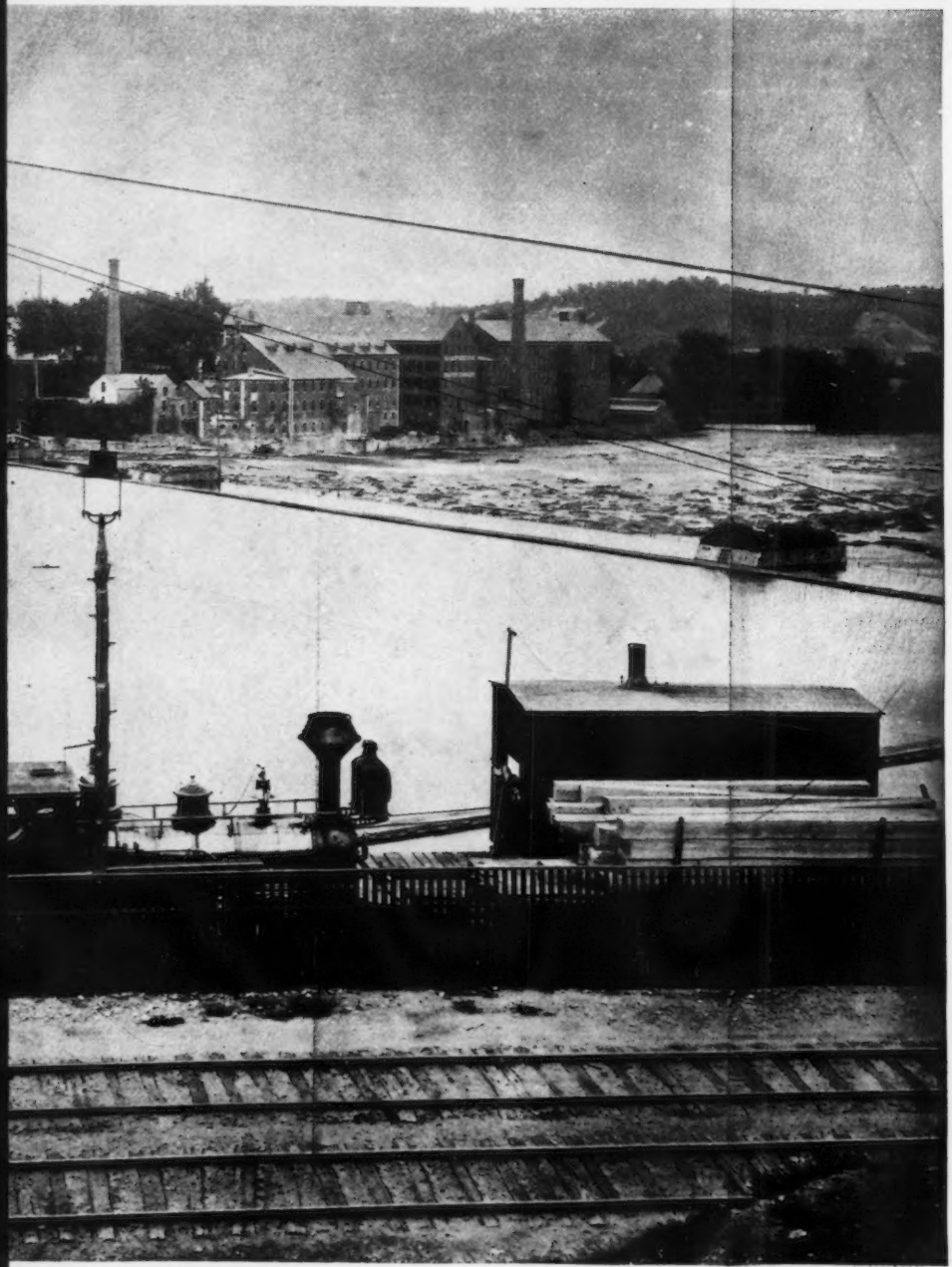


PLATE LXVI.
TRANS. AM. SOC. CIV ENG'RS.
VOL. XV No. 339.
HERSCHEL
ON HOLYOKE DAM.

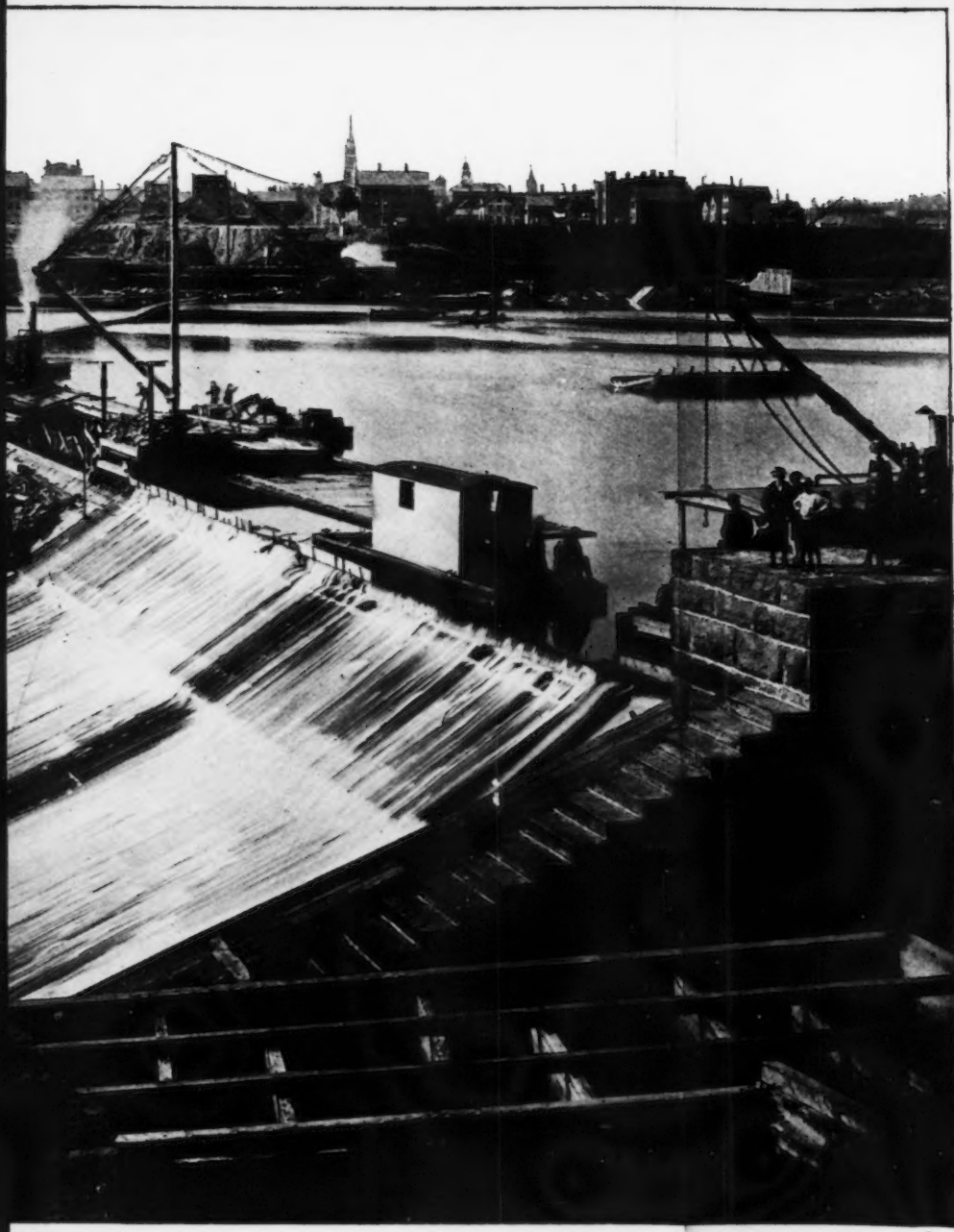


PLATE LXVII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. No. 339.
HERSCHEL
ON HOLYOKE DAM.

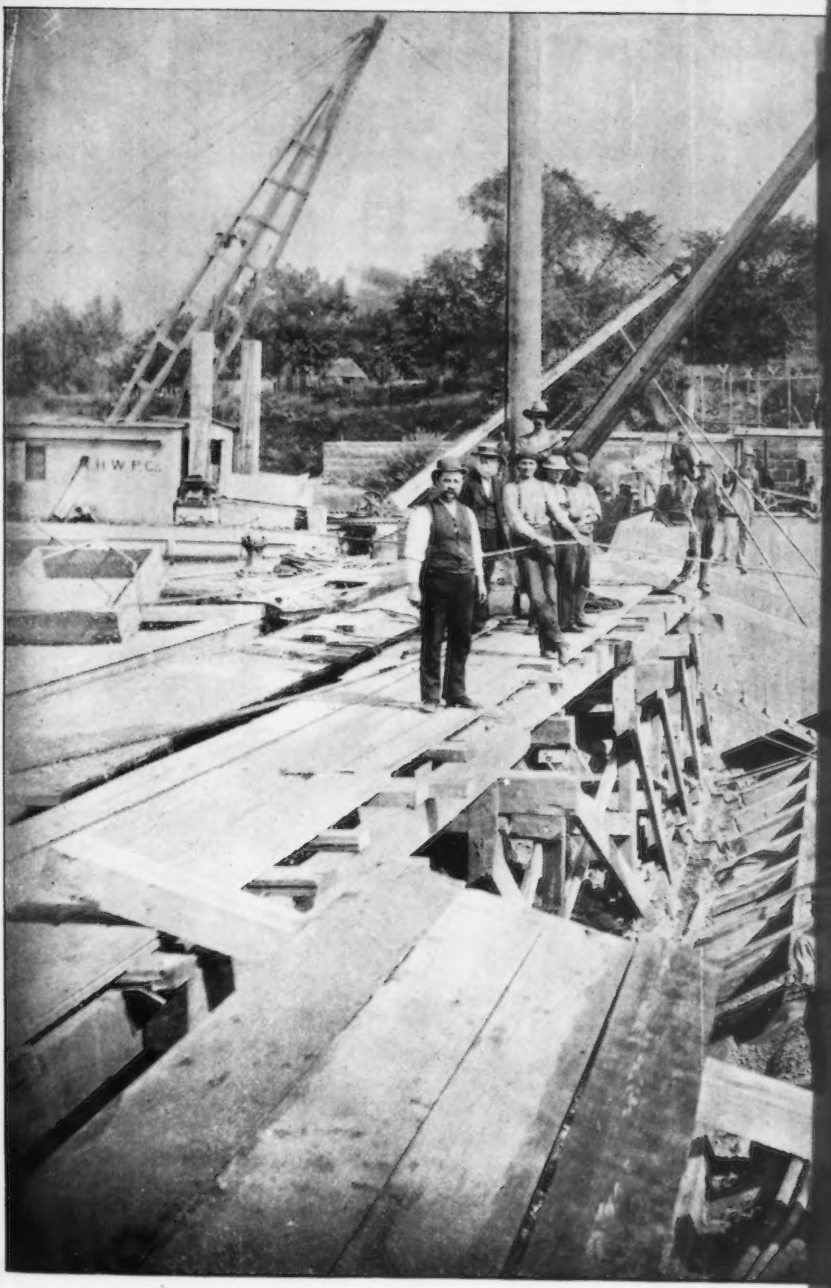

H.W.P.C.

PLATE LXVIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. No. 339.
HERSCHEL
ON HOLYOKE DAM.

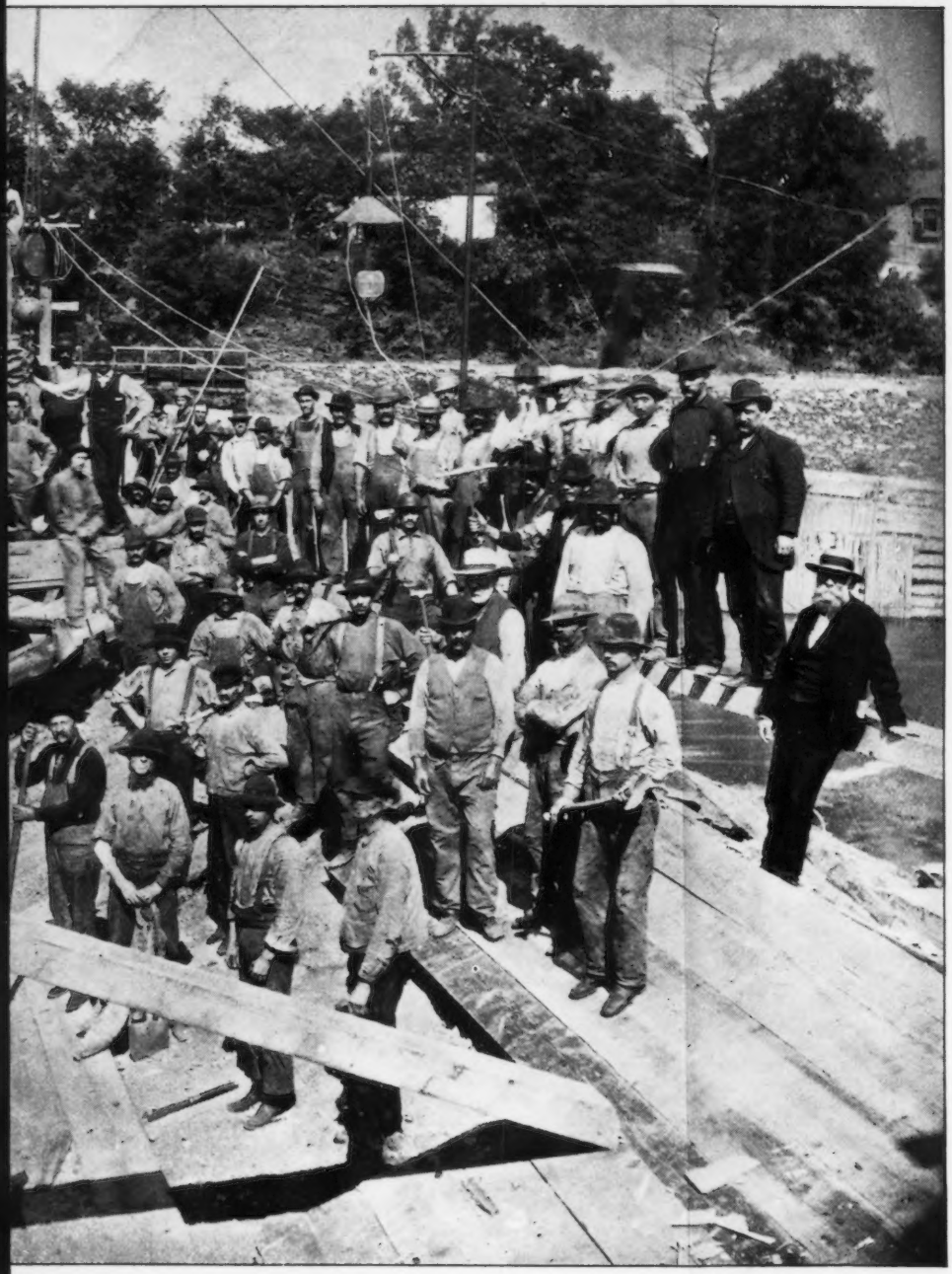


PLATE LXIX.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV. No. 339.
HERSCHEL
ON HOLYOKE DAM.

ERRATA.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

TRANSACTIONS, VOL. XV, JUNE, 1886.—Discussion by George H. Pegram. Page 477. In Table, for the word *Mogul*, read *Class M.* Page 479. Table for Case 3. Third line, fourth column, for 205 414, read 295 414.

TRANSACTIONS, VOL. XV, JULY, 1886.—Johnson on the Strength of Columns. Page 522, in equations (6), (7) and (8), and page 523, in equations (15), (16) and (17), instead of the letter *l*, there should be the figure 1.